PB86-179504

Gas Characterization, Microbiological Analysis, and Disposal of Refuse in GRI (Gas Research Institute) Landfill Simulators

Cincinnati Univ., OH

Prepared for

Environmental Protection Agency, Cincinnati, OH

Apr 86

U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-179504

EPA/600/2-86/041
April 1986

GAS CHARACTERIZATION, MICROBIOLOGICAL ANALYSIS, AND DISPOSAL OF REFUSE IN GRI LANDFILL SIMULATORS

by

Riley N. Kinman, Janet Rickabaugh,
David Nutini, and Martha Lambert
Department of Civil and Environmental Engineering
University of Cincinnati
Cincinnati, Ohio 45221

Contract No. 68-03-3210-12

Project Officer

Joseph K. Burkart
Land Pollution Control Division
Hazardous Waste Engineering Research Laboratory
Cincinnati, Ohio 45268

HAZARDOUS WASTE ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA/600/2-86/041	2.	3. RECIPIENT'S ACCESSION NO. PB86 179504/AS
4. TITLE AND SUBTITLE Gas Characterization, Microbiological Analysis, and Disposal of Refuse in GRI Landfill Simulators		5. REPORT DATE April 1986 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Riley N. Kinman, Janet Rickabaugh, David Nutini, and Martha Lambert		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of Cincinnati Department of Civil and Environmental Engineering Cincinnati, Ohio 45221		10. PROGRAM ELEMENT NO. BRDIA 11. CONTRACT/GRANT NO. 68-03-3210 WA #12
12. SPONSORING AGENCY NAME AND ADDRESS Hazardous Waste Engineering Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/14
15. SUPPLEMENTARY NOTES Project Officer: Joseph K. Burkart		

16. ABSTRACT

This report describes the termination of a five-year pilot-scale project that evaluated methane production and gas enhancement techniques in sanitary landfills. Sixteen simulated landfills were constructed in 1980 and operated until January 1985. Data collected during this termination study consisted of characterization of the trace volatile constituents of the gas generated by the experimental landfills and microbiological analysis of the refuse.

This work was submitted in fulfillment of Contract 68-03-3210-12 by the University of Cincinnati under sponsorship of the U.S. Environmental Protection Agency. This report covers a period from May 1985 through September 1985.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
18. DISTRIBUTION STATEMENT UNCLASSIFIED	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 95
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

DISCLAIMER

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Contract 68-03-3210-12 with the University of Cincinnati. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications.

The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency, the permitting and other responsibilities of state and local governments, and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report describes the microbiology of the refuse in ten experimental landfills that were part of a five-year gas enhancement project. This report also describes the trace constituents of the gas produced by the lysimeters after five years. This information will be useful to individuals pursuing municipal landfill gas utilization, as well as the engineers and government officials involved in landfill operation and land reclamation.

For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

William A. Cawley
Acting Laboratory Director
Hazardous Waste Engineering
Research Laboratory

ABSTRACT

This report describes the termination of a five-year, pilot-scale project that evaluated methane production and gas enhancement techniques in sanitary landfills. Sixteen simulated landfills were constructed in 1980 and operated until January 1985. Data collected during this termination study consisted of characterization of the trace volatile constituents of the gas generated by the experimental landfills and microbiological analysis of the refuse.

The trace volatile organic compounds were found in higher concentrations than previously reported in the literature. Xylenes, ethylbenzene, methylene chloride, toluene, and benzene were found in all of the gas samples analyzed. Xylenes were found in greatest concentrations of the trace compounds analyzed ranging from 12 mg/m^3 to 500 mg/m^3. The levels and types of trace organics found in the gas indicate that landfill gas could be potentially corrosive and may contain toxic levels of some compounds.

All samples had relatively high aerobic and anaerobic plate counts, Clostridium perfringens, and fungi levels. These same samples indicated relatively low levels of total coliforms, fecal coliforms, fecal streptococci, and gram negative rods. Relative numbers and types of microorganisms seemed to reflect the enhancement technique applied to the cell. For example, microorganism levels were generally lower in cells that received leachate recycle as an enhancement technique. The highest level of microorganisms were found in a cell which had a sewage sludge enhancement.

This work was submitted in fulfillment of Contract 68-03-3210-12 by the University of Cincinnati under sponsorship of the U.S. Environmental Protection Agency. This reports covers a period from May 1985 through September 1985.

TABLE OF CONTENTS

Foreword....iii
Abstract....iv
Figures....vi
Plates....vii
Tables....viii
Acknowledgment....ix

1. Introduction....1
   Background....1
   Purpose....4
   Objectives/Work Approach....4
2. Conclusions....9
3. Recommendations....11
4. Procedures....12
   Preliminary....12
   Safety....12
   Test Cell Content Removal....13
   Sampling....13
   Methods of Analysis....17
5. Data and Discussion....21
   GC/MS Analysis of Gas....21
   Microbiology of Refuse....31
   Evaluation of Wastes....42

References....43
Bibliography....44
Appendices

A. Log of Lysimeter Findings....46
B. Micro Media and Reagents....73
C. Quality Assurance....76

FIGURES

Number		Page
1.	Test cell cross section	2
2.	Test cell location plan	3
3.	VOC sampling assembly	14
4.	Trace VOC concentrations: dichloromethane and freon	26
5.	Trace VOC concentrations: dichloroethylene, trichloroethylene, and tetrachloroethylene	27
6.	Trace VOC concentrations: pentane and tetrahydrofuran	28
7.	Trace VOC concentrations: hexane and propylbenzene	29
8.	Trace VOC concentrations: benzene, toluene, and ethylbenzene	30
9.	Trace VOC concentrations: xylenes and carbon disulfide	31
10.	Group 1 organisms: fungi and *Clostridium perfringens*	34
11.	Group 2 organisms: fecal streptococci, clostridia, and gram negative rods	38
12.	Methane bacteria after 60-day incubation	41

PLATES

Number		Page
1.	Truckload of coarse ground refuse	16
2.	First one-foot lift of refuse compacted in test cell	16

TABLES

Number		Page
1.	Refuse physical composition	4
2.	Enhancement techniques	5
3.	Target volatile organic compounds	6
4.	Cells selected for gas characterization and microbiological analyses	7
5.	Analysis summary and final test cell disposition	8
6.	Microbial sample depths	17
7.	Media and incubation conditions	20
8.	Trace VOC concentrations in blanks	23
9.	Trace VOC concentrations (cells 21, 22, 23)	24
10.	Trace VOC concentrations (cells 33 and 35)	25
11.	Microbiological sample moisture contents	32
12.	Group 1 microorganisms (SPC, CP, Fungi)	35
13.	Mean leachate volatile acids, 1984	36
14.	1984 cumulative gas production rates	37
15.	Group 2 microorganisms (fungi and Clostridium perfringens)	39
16.	Group 2 microorganisms (fecal streptococci, clostridia, and gram negative rods	40

ACKNOWLEDGMENT

The authors would like to extend their appreciation to those people who have contributed to this work through their guidance, work effort, and patience.

A special thanks is given to Joseph Burkart, the project officer, and to Herbert Pahren, both of the U.S. EPA.

From the University of Cincinnati, the analyst staff and support personnel consisted of Susan Pierce, Sam Hayes, Annette DeHaviland, Regina White and Kevin Frank, the microbiology staff; Bob Mackey, gas sampling; Hildred Somme, laboratory analyses; and Pat Miller, the Q.A. and procurement officer.

SECTION 1

INTRODUCTION

This report describes the termination of a five-year, pilot-scale sanitary landfill project that evaluated methane production and gas enhancement techniques in sanitary landfills. The project was housed at the U.S. EPA Center Hill Solid and Hazardous Waste Research Facility in Cincinnati, Ohio, but was funded by the Department of Energy (DOE) from February 1980 through January 1982, by the University of Cincinnati from February 1982 through January 1983, and then by the Gas Research Institute (GRI) from February 1983 through April 1985. The termination of the study, which this report describes, was performed for the U.S EPA by the University of Cincinnati, Department of Civil and Environmental Engineering. A final report describing the results of the five-year gas enhancement study has recently been published and is available from the Gas Research Institute.[1]

BACKGROUND

In January 1980, sixteen laboratory-scale lysimeters were loaded with shredded municipal refuse. Each lysimeter was constructed of steel six feet (1.83m) high by three feet (0.91m) in diameter and designed to contain one cubic yard of shredded refuse. The inside steel walls were coated with coal tar epoxy to prevent corrosion. The lysimeters were set on concrete blocks to allow convenient access to the leachate drainage systems. A cross section of the test lysimeters can be seen in Figure 1. Detailed information on the design and construction of the lysimeters is available in the literature[1,2].

The cells were loaded with refuse in a series of one-foot lifts. Table 1 describes the refuse composition as determined from handsorting the refuse prior to shredding. Gravel was placed at the bottom and top layers to assist in drainage and in moisture distribution. Complete leachate drainage and gas monitoring systems were installed as shown in Figure 1. Lysimeter covers were welded shut and sealed to ensure the cells were gastight, as well as leachate-tight.

The test lysimeters were located in the high bay area of the Center Hill facility, where controlled conditions were monitored at all times (Figure 2). Cells were numbered consecutively from 20 to 35. The enhancement techniques investigated included moisture addition, elevation of temperature, leachate recycle, sewage sludge addition, buffer addition, and nutrient addition. Several years into the study, the cells were reloaded with different or additional enhancements. Cells were originally paired, each pair receiving the same enhancement technique. When cells were reloaded, half of the cells

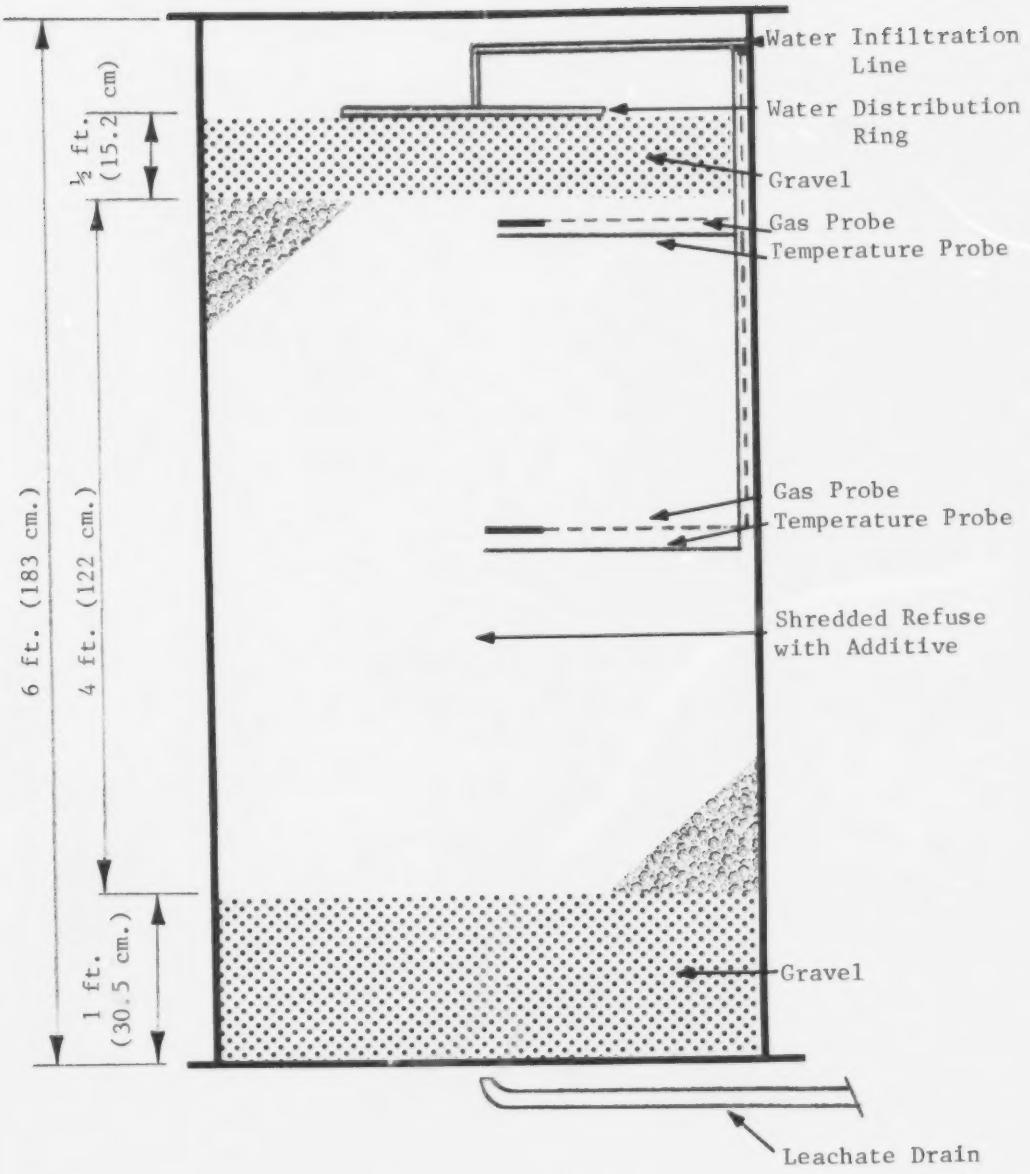

Figure 1. Test Cell Cross Section

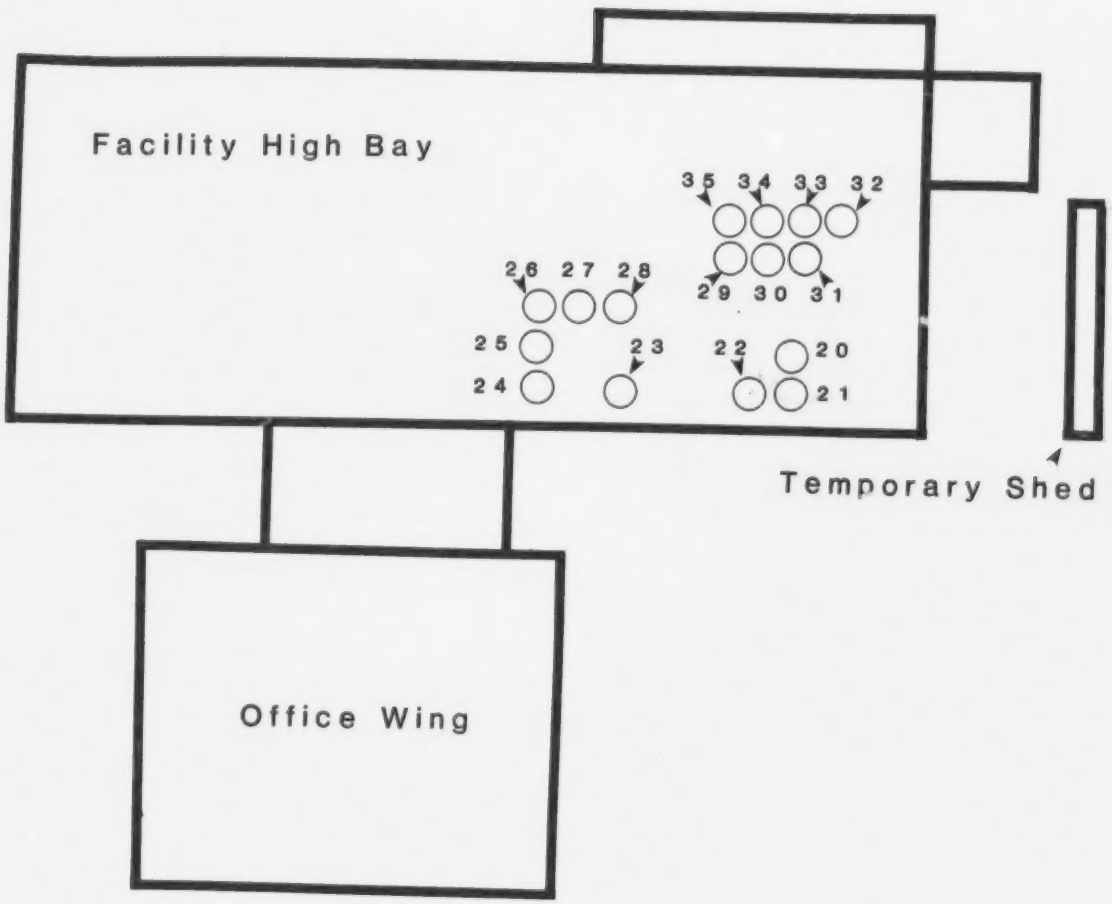

Figure 2. Test Cell Location Plan

TABLE 1. REFUSE PHYSICAL COMPOSITION

COMPONENT	PERCENT (Wet Weight)
Paper	51.70
Food Waste	7.23
Fines*	6.99
Plastic	6.79
Glass	5.96
Ferrous Metal	5.15
Textiles	4.74
Garden Waste	3.66
Wood	3.00
Diapers	2.23
Non-Ferrous Metal	1.37
Ash-Rock-Dirt	0.67
Rubber-Leather	0.54

*Material passing through a 25mm (1 inch) sieve

received no change in order to maintain a control for the reloaded cells and to continue with the original project, started in 1980. Table 2 summarizes the enhancement techniques applied to each of the test lysimeters throughout the study.

PURPOSE

The purpose of this lysimeter performance study was to characterize the quality of the gas produced in specific selected cells, evaluate the number and groups of active organisms within the municipal solid waste, and to dispose of the contents of the cells which were opened. Six of the sixteen cells were not opened and remain active for a lime injection/gas production prevention study.

WORK APPROACH

In order to evaluate the test lysimeters as described, specific objectives were established. There were three main objectives, or tasks, involved with this project: 1) gas characterization, 2) microbiological analyses, and 3) cell contents disposal.

The specific cells selected for each task, as well as the detailed work approach employed, are described below.

TABLE 2. ENHANCEMENT TECHNIQUES

TEST CELL	ENHANCEMENT TECHNIQUE Feb.'80 - Jan.'82	ENHANCEMENT TECHNIQUE Feb.'83 - Jan.'85
20	Low Infiltration	No Change
21	Low Infiltration	Increase Moisture Content
22	High Infiltration	No Change
23	High Infiltration	No Change
24	High Infiltration, Leachate Recycle	No Change
25	High Infiltration, Leachate Recycle	Sludge Addition
26	High Infiltration, Leachate Recycle, Buffer Addition	No Change
27	High Infiltration, Leachate Recycle, Buffer Addition	Sludge Addition
28	High Infiltration, Leachate Recycle, Nutrient Addition	No Change
29	High Infiltration, Leachate Recycle, Nutrient Addition	Sludge Addition
30	High Infiltration, Leachate Recycle, Buffer Addition, Nutrient Addition	Temperature Increase
31	High Infiltration, Leachate Recycle, Buffer Addition, Nutrient Addition	Temperature Increase
32	High Infiltration, Buffer Addition	No Change
33	High Infiltration, Buffer Addition	Buffer Slurry Addition
34	High Infiltration, Nutrient Addition	No Change
35	High Infiltration, Nutrient Addition	Nutrient Slurry Addition

Gas Characterization

The five-year gas enhancement project collected large volumes of data on overall gas composition. Gas samples were monitored monthly for percentage of O_2, N_2, CO_2, and CH_4. There was no attempt to analyze the trace constituents of the gas. Table 3 lists twenty volatile organic compounds (VOC) which have been repeatedly observed in landfill gas and which are considered to be characteristic trace components at full-scale landfill sites. These VOCs were selected for further investigation during this lysimeter termination study and consisted of some priority pollutant compounds, known carcinogens, and other compounds of environmental concern. Normal alkanes (pentane, nonane, etc.) were included to provide baseline data.

TABLE 3. TARGET VOLATILE ORGANIC COMPOUNDS

COMPOUND NAME	SYNONYM	MOLECULAR WEIGHT
Pentane		72
Benzene		78
Dichloromethane	Methylene chloride	85
Hexane		86
Toluene	Methylbenzene	92
1,1-Dichloroethylene	Vinylidene chloride	97
1,2-Dichloroethylene		97
1,1-Dichloroethane		99
m,p-Xylene		106
o-Xylene		106
Ethylbenzene		106
Chlorobenzene	Monochlorobenzene	113
Iso-Octane		114
Isopropylbenzene	Cumeme	120
Propylbenzene		120
Naphthalene		128
Nonane		128
Trichloroethylene	TCE	131
1,1,2-Trichloroethane	Vinyl trichloride	133
Tetrachloroethylene	Perchloroethylene	166

These VOCs were selected for study because it was felt that they would provide a characteristic measure of the potential environmental and health concerns associated with landfill gas recovery, utilization, and exposure.

Five of the higher gas-producing cells (as measured by total gas volume in January 1985) were selected for gas characterization. These cells can be seen in Table 4. Information on the gas production from the cells can be found in the five-year report.

Task 2: Microbiological Analyses

Microbiological analyses were performed on samples collected at two depths from six of the sixteen test lysimeters. These six cells were selected as representative of the various enhancement techniques used on the sixteen cells. The six cells selected for microbiological investigations can be seen in Table 4.

TABLE 4. CELLS SELECTED FOR GAS CHARACTERIZATION AND MICROBIOLOGICAL ANALYSES

GAS CHARACTERIZATION TEST CELLS	ENHANCEMENT TECHNIQUE*
21	Control/Increase Moisture@
22	High Infiltration/No Change
23	High Infiltration/No Change†
33	High Infiltration, Buffer Addition/Buffer Slurry Addition
35	High Infiltration, Nutrient Addition/Nutrient Slurry Addition
MICRO ANALYSIS TEST CELLS	**ENHANCEMENT TECHNIQUE***
20	Control/No Change@
23	High Infiltration/No Change
25	High Infiltration, Leachate Recycle/Sludge Addition
26	High Infiltration, Leachate Recycle, Buffer Addition/ No Change
30	High Infiltration, Leachate Recycle, Buffer Addition Nutrient Addition/Temperature Increase
35	High Infiltration, Nutrient Addition/Nutrient Slurry Addition

*Original Loading/Reloading
@Waste spiked with benzene, toluene, and ethylbenzene
†Only one gas sample taken; cell emptied prior to second sampling

The microbiological studies performed included:

1. Enumeration of total heterotrophic plate count for aerobic and anaerobic bacteria
2. Examination of anaerobic bacteria for methane-producing bacteria
3. Examination for and enumeration of Clostridium bacteria

4. Examination and enumeration of fungi

5. Enumeration of the indicator organisms: total coliforms, fecal coliforms, and fecal streptococci

Cell Contents Disposal

The contents of the following ten cells were disposed of during this study: 20, 23, 24, 25, 26, 28, 30, 31, 34, and 35. The waste from each lysimeter was carefully examined during the emptying process. Each emptied lysimeter was rinsed and cleaned in preparation for storage until needed for a future project. Six of the sixteen test cells (21, 22, 27, 29, 32, and 33) remain active for further evaluation as part of a lime injection/gas prevention study. Table 5 summarizes the analyses performed and the final disposition of each cell.

TABLE 5. ANALYSIS SUMMARY AND FINAL TEST CELL DISPOSITION

TEST CELL	MICRO	GC/MS	DISPOSAL	LIME INJECTION STUDY
20	M		D	
21		G		L
22		G		L
23	M	G	D	
24			D	
25	M		D	
26	M		D	
27				L
28			D	
29				L
30	M		D	
31			D	
32				L
33		G		L
34			D	
35	M	G	D	

SECTION 2

OBSERVATIONS AND CONCLUSIONS

CELL CONTENTS

1. All test cells were in excellent condition. Seals were intact and the cells were gastight. Copper fittings had a buildup of sulfide on them. Bottom and top gravel removed from the cells was clean and in excellent condition.

2. There was settlement in each of the lysimeters. The greatest settlement observed was five inches, which occurred in test cell 25.

3. Only a small fraction of the total ground refuse mass was decomposed after five years in the test cells. This fraction was believed to be the food wastes. Refuse in test cell 25, which had received leachate recycle and anerobically digested sludge, appeared to be the most degraded.

4. Artifacts were difficult to isolate and identify in the ground refuse. However, those artifacts that were found documented the resistance to biological attack of plastic, paper, rubber, leather, dyes, synthetics, metal, plated metal, stainless steel, wood, glass, stone, and combinations of these materials.

5. All of the test cells had bits and pieces of readily biodegradable material that had been protected by the plastics and paper. Pieces of newsprint could still be read, although biological attack was noted on some. Cloth materials were still strong and retained their colors.

LYSIMETER GAS

6. Trace volatile organic compounds were found in higher concentrations than previously reported in the literature.

7. Xylenes were found in greatest concentrations as determined by GC/MS analysis of the lysimeter gas for trace volatile organic compounds. Concentrations ranged from 12 mg/m^3 to 500 mg/m^3 in the gas samples analyzed.

8. Xylenes, ethylbenzene, dichloromethane (methylene chloride), toluene, and benzene were found in every gas sample analyzed.

9. Concentrations of 1,1-dichloroethane, chlorobenzene, iso-octane, isopropylbenzene, naphthalene, nonane, and 1,1,2-trichloroethane were below detectable limits in the gas samples from all lysimeters tested.

10. GC/MS analysis confirmed the presence of chlorinated volatile trace organic compounds in landfill gas generated from municipal refuse.

MICROBIOLOGY

11. Relative levels and types of microorganisms found in those cells analyzed seemed to reflect the enhancement technique applied to the cell. The highest levels and the most different types of microorganisms were found in cell 25, which had a sludge addition enhancement, and then in cell 35, which had a nutrient addition enhancement.

12. Microorganisms evaluated were generally lower in concentration in the leachate recycle cells. This suggests that toxicity effects were exerted after the leachate was recycled many times.

13. Total coliforms, fecal coliforms, and fecal streptococci were found in the lowest levels of the microorganisms evaluated. Most of the samples analyzed indicated no counts for these organisms at the lowest dilutions tested.

14. There were relatively high levels of both aerobic and anaerobic pathogenic and non-pathogenic microorganisms present in the refuse after five years of disposal.

SECTION 3

RECOMMENDATIONS

1. Sewage sludge should be evaluated further for methane gas enhancement in municipal landfills.

2. Protective mechanisms which prevent readily biodegradable material from biological attack should be evaluated.

3. Volatile organic compounds in landfill gas should be studied over a longer time period.

4. Corrosion effects from burning landfill gas with the trace chlorinated organic compounds should be evaluated.

5. Landfill gas combustion decomposition products should be evaluated for their toxicity effects.

6. Leachate recycle needs further evaluation to determine at what number of recycles the toxicity effects come into play.

7. Concentrations of VOCs observed should be evaluated as to their health effects in processing and in use of the gas.

SECTION 4

PROCEDURES

PRELIMINARY

Prior to opening any of the test cells, they were moved from the Center Hill high bay area to a temporary shed located outside of the high bay overhead door. The plywood shed was built for lysimeter unloading activities from a previous project and offered a protected work area and secure storage for the opened cells. Each cell was moved, opened, unloaded, and rinsed prior to beginning the sequence on the next cell.

Moving Test Cells

Before the cells could be moved, all electrical probes, outer gas lines, and gas collection bags were removed. The fiberglass insulation that surrounded the cells was also removed. The cell was lifted off its cement block supports using hydraulic jacks. Two steel I-beams were set under the cell and run to a heavy-duty cart positioned next to the cell. The test cell was carefully rolled across the I-beams onto the cart. Cement blocks were repositioned under the cell, and the I-beams were removed. The cart was then slowly rolled out of the high bay area into the temporary storage shed. The cell remained on the cart throughout the unloading activities.

SAFETY

After the cell was in the shed it was filled with water via the water inlet line to force methane gas from the cell. This was done to eliminate potentially explosive levels of methane prior to cutting the lysimeter lids off with an acetylene torch. While the lids were actually being cut, the base of the cell was continually hosed with water to cool hot metal scrap from the lid. A fire extinguisher was kept on hand at all times.

Protective clothing worn for the excavation procedures consisted of steel-toed rubber boots, coveralls, particle masks, and disposable polyethylene gloves under cotton work gloves. After work each day, all clothing was removed on-site at the decontamination station.

Portable stairs were placed next to the cell being emptied for easy access from the ground to the top of the cell. A step ladder was used to actually enter or exit the cell. A wood beam with a line was placed over the cell being emptied as an emergency evacuation aid.

TEST CELL CONTENT REMOVAL

Once the lids of the test cells were opened, the copper probes and the water infiltration hose and ring were disconnected and removed from the cell. Notations were made on the conditions of these probes, the appearance of the coarse gravel at the top of the cell, and the conditions of the tank sidewalls. The distance from the top of the cell to the top of the gravel was measured. The water was drained from the cell through the leachate drainage system. The gravel was removed by digging it out with a shovel and handpicking the remainder. The gravel was placed in containers on a skid held by a forklift next to the cell. Once all the gravel was removed, it was transported to a dumpster on the Center Hill site. After all of the cells were emptied, the dumpster was transported to a sanitary landfill for final disposal.

When all of the gravel was removed, the distance from the top of the lysimeter to the top of the refuse was measured. The refuse was removed in layers by scraping the contents with a pitch fork or cultivator. The loose refuse was piled toward the center of the cell. The excavator would then pick up the loose refuse by hand and place it into a trash container on a skid set on the forklift. Once the refuse was on the skid, another person would sort through the contents for artifacts as well as note conditions of waste materials. Once these containers were full, they were transported to the dumpster.

After the refuse was removed, a final measurement was made from the top of the lysimeter to the top of the bottom gravel layer. The bottom gravel was removed from the cell in buckets much the same as the other materials and transported to the dumpster with the forklift. The cell was triple-rinsed with water after all contents had been removed.

SAMPLING

Gas Sampling

The gas sampling of the test cells for the target VOCs used absorbent resin columns termed Tenax traps. These Tenax traps were clear glass cylinders approximately 1.5 cm in diameter and 14 cm long. They were furnished by Pedco Environmental, Incorporated (PEI), who was subcontracted to perform the GC/MS analyses. The traps were picked up from PEI the day prior to sampling and returned the next day immediately after sampling was completed. The traps were prepared by heating to 180°C with flow for sixteen hours. They were then placed in individual glass vials, wrapped with tissue paper, and placed in a can containing activated carbon and silica gel. Each trap had its own number etched into it, and the same number was found on the outside of the glass vial that contained it.

The equipment used for the sampling included teflon tubing, fine metering valve, toggle shutoff valve, bubble flow meter, pump and Tenax traps. Figure 3 illustrates the entire VOC sampling assembly. A portable vacuum pump was only used for the sampling of a blank air sample for analysis. Due

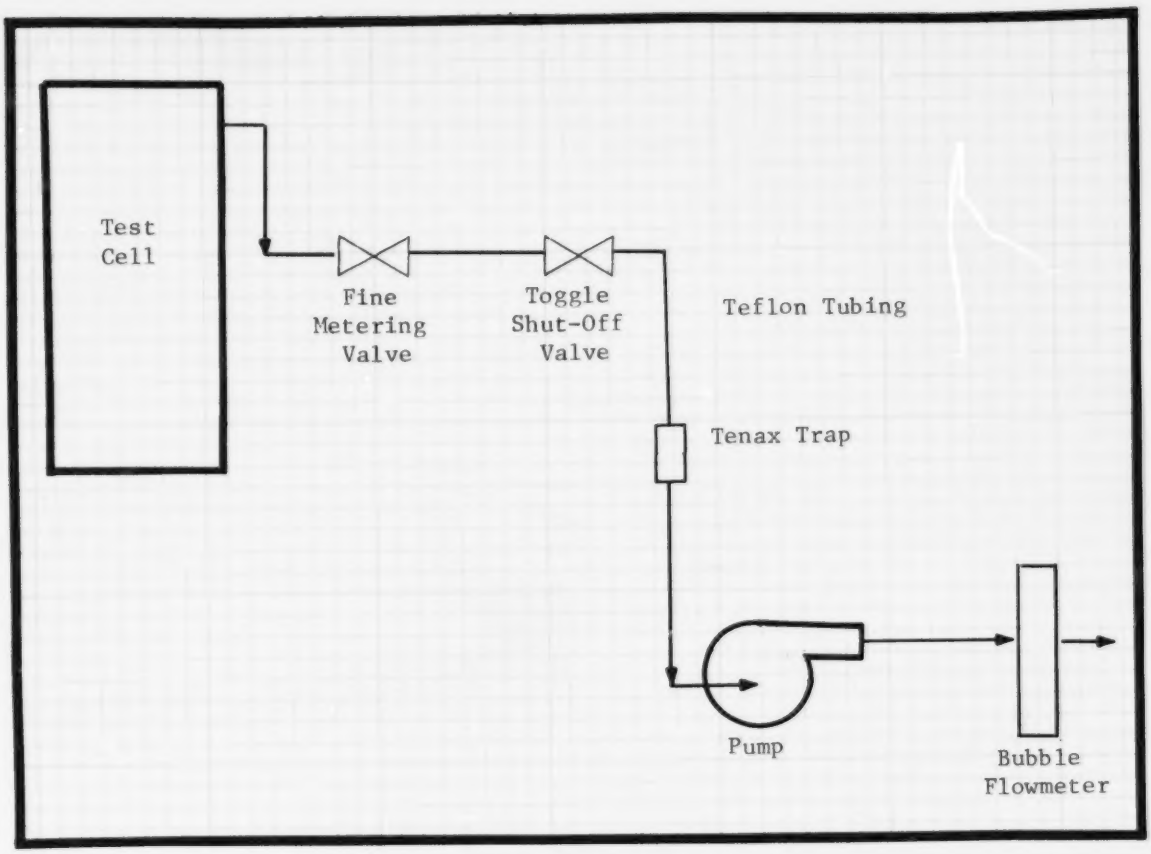

Figure 3. VOC sampling assembly

to difficulties encountered eliminating leaks between the different tubing for the pump, the decision was made to delete the pump in the assembly. Since the sample volume was very small and the test cell had sufficient pressure to furnish its own flow, the pump was not needed.

A gas chromatography-type bubble flow meter was used to calibrate the gas flow through the Tenax trap. A 10 ml bubble flow meter allowed for accurate measurement of the desired 7 ml to 30 ml/minute sampling flow rate.

The initial setup of the assembly did not include the trap. All lines were connected and the flow was adjusted with the fine metering valve to give an accurate flow measurement using the bubble flowmeter. Water was found in most of the regular gas measuring ports, and concern for any damage to the sample traps warranted use of the water inlet line for this sample procedure.

In the final setup the Tenax trap was added and the toggle valve opened. A flow rate was taken every minute and recorded. Temperature and barometric pressure at the time of sampling were also noted. The toggle valve was turned off when the desired volume of gas had passed through the trap.

The first gas samples were collected on May 22, 1985, and again on May 29, 1985. Each sampling day provided samples from the five test cells designated for gas characterization (21, 22, 23, 33, and 25), one randomly selected duplicate, and a blank.

At first, 2-liter gas samples were collected at ambient conditions. The selection of the 2-liter volume was based on similar gas sampling from an on-going lysimeter study at the U.S. EPA Test and Evaluation Facility in Cincinnati, Ohio. Actual original gas sample volumes at standard temperature and pressure ranged from 1.6 to 1.9 liters. Initial GC/MS results from two of the five samples (cells 21 and 23) obtained May 22, 1985, indicated that the 2-liter sample volume was too high. Many of the compounds of interest were present in concentrations that were too high to quantify in those samples. Furthermore, the samples were very "dirty" and the GC/MS encountered difficulties actually analyzing the samples. Therefore, new gas samples of lower volumes were collected on June 26, 1985, and July 1, 1985. Unfortunately cell 23 was emptied prior to the decision to take lower volume gas samples. It was analyzed at the higher sample volume, however, so some characterization data was obtained for that cell.

An additional piece of information taken into consideration in determining the sample volume of the second set of gas samples was the fact that cell 21 had been spiked with 39 grams of benzene, 37 grams of ethylbenzene, and 32 grams of toluene when the cell was originally loaded. All of these compounds were designated as target VOCs for this project. This spiking was done in conjunction with Ph.D. dissertation research by Janet Rickabaugh, which is expected to be published in the Spring of 1986. Gas sample volumes collected during the second sampling period were 25 ml for cell 21 and 100 ml for cells 22, 33, and 35. A second gas sample set contained samples from cells 22 and 33 only.

After samples were collected, they were sealed in a metal can containing silica gel and delivered to PEI by U.C. sampling personnel.

Microbiological Sampling

Samples were taken at two levels in each of six test cells. A top sample was taken approximately 12 inches (30 cm) into the refuse. A second sample was taken at approximately 45 inches (114 cm) into the refuse, near the bottom gravel. These samples were described as top and bottom, respectively. Table 6 contains the test cell sample number and the depth into the refuse for each sample.

All of the micro samples were a composite of five grab samples which were taken at different locations across the sampled layer. This was accomplished by peeling back the layer to be sampled and quickly grabbing a sample. It should be noted here that although the refuse was ground, this was a coarse grinding that maintained a particle size of about 1-1/2 to 2-1/2 inches (3.8 to 6.4 cm) (Plates 1 and 2). Furthermore, large items such as cans, plastic bottles, etc., were not necessarily shredded into neat 2-1/2 (6.4 cm) inch pieces. Often the items were balled into fist-sized clumps which were then

small enough to pass through the grinder. These large inert items were intentionally avoided in the micro sampling. The total composite sample was approximately 1 kilogram. As soon as the sample was taken, it was placed in a new zip-lock plastic bag. Air was squeezed out of the bag to minimize oxygen. Samples were transported to the University of Cincinnati in coolers, where any oxygen in the sample was displaced with nitrogen. All samples were processed within 96 hours.

Plate 1. Truckload of coarse ground refuse

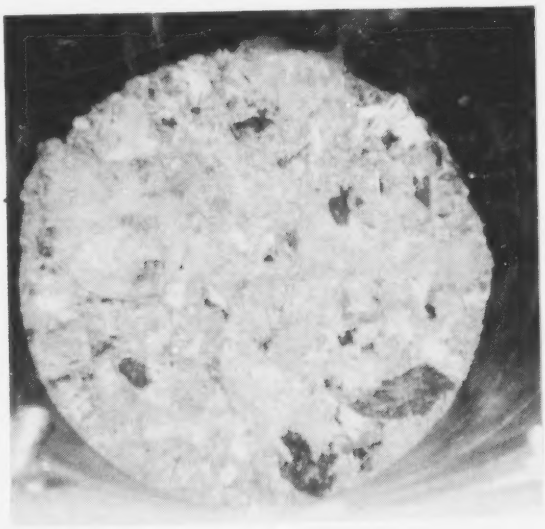

Plate 2. First one-foot lift of refuse compacted in test cell

TABLE 6. MICROBIAL SAMPLE DEPTHS

TEST CELL	DEPTH FROM TOP TO REFUSE (inches)	(cm)	SAMPLE A DEPTH INTO REFUSE (inches)	(cm)	SAMPLE B DEPTH INTO REFUSE (inches)	(cm)
20	15	38	12	30	45	114
23	16	41	18	46	44	112
25	19	48	13	33	41	104
26	15	38	11	28	45	114
30	16	41	11	28	44	112
35	16	41	11	28	44	112

METHODS OF ANALYSIS

Gas Characterization

The volatile organic compounds were analyzed by GC/MS using EPA Method 624. The contents of the sample traps were spiked with 5 microliters of internal standard. This internal standard was composed of bromochloromethane, 1,4-diflourobenzene, and d_5-chlorobenzene. After the traps were spiked with the internal standard, they were thermally desorbed for ten minutes at 180°C with organic-free nitrogen bubbled through 5 ml of organic-free water and trapped on an analytical trap. After the ten-minute desorption, the analytical adsorbent trap was rapidly heated to 180°C with carrier gas flow reversed so that the effluent flow from the analytical trap was directed onto a 6-foot glass column packed with SP-1000 on Carbopack B. The volatile organic compounds were separated by temperature-programmed gas chromatography and detected by low resolution mass spectometry. The mass of the compounds present was calculated using the internal standard technique.

Microbiology of Refuse

Biological Safety Hood. An anaerobic safety hood consisting of a plastic cabinet with aluminum framing and outside dimensions of 60 x 92 x 46 cm was used for this study. The unit contained several gas port holes, two rubber gloves, a clear viewing plastic window, and two zippered entrances. During use, the cabinet was filled with carbon dioxide to lessen the effect of oxygen on the solid waste sample. All samples were weighed and homogenized in a Waring blender within the hood and allowed to sit for one-half hour to permit condensation of atomized water droplets. Before opening the cabinet doors, the gas was vented into an iodine-filled flask to decrease the danger of worker pathogen inhalation.

Sample Homogenization and Diluents. For microbial studies, solid waste was initially blended with sterile 0.1% peptone water (Standard Methods, 1981) for a 1:9 (10%) dilution. Thus, 30 or 40 grams of solids were added to 270 or 360 ml of sterile diluent. When early results indicated no organism growth, a lower dilution was used. Sixty or eighty grams of solids were added to 240 or 320 ml of sterile diluents for a 1:4 (20%) dilution. Samples were homogenized in the Waring blender at high speed for fifteen seconds within the nitrogen-filled anaerobic hood. The homogenate was allow to sit for thirty minutes to permit condensation of atomized water droplets. The hood was then evacuated, and the air forced through an iodine trap to remove any pathogen-containing water droplets. Following this, the waste samples were serially diluted with 0.1% sterile peptone water in preparation for the inoculations.

Anaerobic Cultivation Techniques. All plates used for anaerobic studies (blood, Standard Methods, and egg yolk agars) were pre-reduced with carbon dioxide in a sealed container for at least two hours. Following sample inoculation, these plates were returned to the carbon dioxide gas chamber in an upright position for one-half hour, allowing the agar time to absorb the inoculum. Then plates were inverted and incubated in a BBL GasPak (BBL) jar for 24 to 48 hours. All GasPak (BBL) jars were made anaerobic with disposable BBL hydrogen/carbon dioxide generator envelopes.

When tubed media were to be incubated anaerobically, they were first heated in a boiling water bath and cooled. Following the tube inoculation, sterile mineral oil was added to the media surface to a height of at least 1 cm to maintain anaerobic conditions.

Microbiological Enumeration Procedures

Total and Fecal Coliforms (Standard Methods - 909). Total and fecal coliforms were determined by the most probable number (MPN) procedures (Standard Methods - 909). Ten ml to 10^{-5} ml of the diluted homogenized sample were inoculated into five tubes per dilution of lauryl sulfate broth. Following a 48-hour incubation at 35°C, two drops from each positive tube were inoculated into brilliant green bile broth and EC tubes. All media were incubated using the procedure described in Standard Methods (1981). The completed test was carried out for all positive tubes of all samples. To determine final concentrations, the number of positive tubes were converted to MPN values using the Standard Methods (1976) MPN Index Table.

Fecal Streptococci (Standard Methods - 910). Five tubes per dilution of azide dextrose were inoculated with 1.0 ml to 10^{-5} ml of homogenized sample. Following the 48-hour incubation, all positive tubes were streaked onto PSE agar. The confirmatory test and final streptococcal concentration calculations were carried out according to procedures described in Standard Methods, and the number of positive tubes were converted to MPN values using the Standard Methods (1976) MPN Index Table.

Clostridium perfringens (Koneman et al., 1979; Dowell and Hawkins, 1976). Stormy fermentation of iron milk was used as an MPN fecal indicator test to determine the concentration of anaerobes, especially of Clostridium perfringens, in solid waste (Donnelly and Scarpino, 1984). The medium chosen was iron skim milk (Bonde, 1963; Dowell and Hawkins, 1976). This was a five-tube test to which 1.0 to 10^{-5} ml of diluted inoculum was added, followed by the aseptic addition of sterile mineral oil to each tube to a 1 cm height. Tubes were incubated at 35°C for 48 hours and read for coagulation and gas production. To confirm the presence of Clostridium perfringens, 10% to 20% of positive tubes per sample were streaked onto blood agar plates and examined for the presence of double-zone hemolysis, signaling the presence of this anaerobe.

Plate Count Procedures. All plate counts were made by the spread plate technique. In preparation for plating, the diluted homogenates were Vortex-mixed. A 0.1 solution portion from each dilution tube was added to duplicate plates and spread with a sterile bent glass rod (Bordner et al., 1979; Koch, 1981). A one-half hour incubation period at room temperature followed the inoculations, allowing the agar media time to absorb the inoculum. Then the plates were inverted and incubated at 35°C for a 48-hour period. Anaerobic plates were kept in a carbon dioxide chamber during this half-hour period prior to anaerobic incubation in a GasPak jar. All plates and incubation periods are listed in Table 7.

Total Plate Counts. Standard Methods agar was the medium used for total plate counts. Following inoculation with the serially diluted samples, plates were incubated both aerobically and anaerobically to give some measure of total aerobic and anaerobic bacterial counts.

Clostridium (Duncan and Harmon, 1976). Tryptone sulfite cycloserine agar served as the growth medium for Clostridium plate counts.

Fungi. All fungi, including both yeasts and molds, were enumerated on rose bengal agar. This medium and the procedure for its use are given in Standard Methods (1981).

Gram Negative Rods. MacConkey agar was used to determine the gram negative rod plate counts. Following the sample inoculation, the plates were incubated at 35°C for a 24-hour period.

Additional Microbial Analyses

Methane-Producing Bacteria. A methanogenesis medium was used to detect methane gas (Donnelly and Scarpino, 1984). The inoculum added to this medium contained 5 grams of solid waste, or 5 mls of the serially diluted homogenate, to a final dilution of 10^{-4}. Escherichia coli inoculum and $NaHCO_3$ were also

TABLE 7. MEDIA AND INCUBATION CONDITIONS

TYPE OF MEDIUM	TYPE OF MICROORGANISM SELECTED
MPN Test Broths/Agar	
Lauryl sulfate[a]	Total and fecal coliform
Brilliant green bile[a]	Total coliform
EC[b]	Fecal coliform
Azide dextrose[a]	Fecal *Streptococcus*
PSE[b]	Fecal *Streptococcus*
Iron milk	*Clostridium perfringens*
Enrichment Broths	
Methanogenesis[c]	Methane-producing bacteria
Enumeration Agars	
Standard Methods - aerobic[a]	Total plate counts - aerobic
Standard Methods - anaerobic[a]	Total plate counts - anaerobic
MacConkey[b]	Gram negative rods
Tryptone sulfite cycloserine[a]	*Clostridia*
Rose bengal[d]	Fungi

[a] 35°C, 48 hours
[b] 35°C, 24 hours
[c] 35°C, 30-90 days
[d] room temperature, one week

added at this time, as described in Appendix B. The *E. coli* was added to metabolize food materials and to deplete oxygen levels. Following these additions, vials were flushed with 30% hydrogen gas and 70% carbon dioxide for thirty seconds, sealed, and incubated at 35°C for one to three months. Duplicate vials were used for each dilution.

The gases in these vials were measured using a Perkin-Elmer 900 chromatograph. For the analysis, up to three-milliliter-volumes of sample gas were compared to the same volume of a standard gas. The standard gas used was from Matheson Gas Co. (Dayton, Ohio) and contained 16.47% N_2, 4.15% O_2, 34.71% CO_2, and 44.67% CH_4. The analysis was normalized to 100%, based on the presence of CH_4, CO_2, O_2, and N_2 in the sample (McNair and Bonelli, 1969). A computer program was used for individual sample calculations.

SECTION 5

DATA AND DISCUSSION

GAS ANALYSIS

Landfill gas may be used as an alternate source of energy in order to conserve natural gas reserves. The purpose of the original project was to enhance the quantity and quality of the gas produced in the anaerobic landfill setting. One problem with landfill gas is that it may contain trace gases that will not support combustion and may in fact create problems from incomplete combustion products. These problems may range from simple lowering of gas BTU values to complex thermal decomposition products that would pose a threat to users of the landfill gas. Hence the rationale for GC/MS analysis of the trace organics in the gases from these experimental landfills.

A spike of volatile organic compounds was placed in test cells 20 and 21 to provide a baseline for the GC analysis and GC/MS analysis reported here. These two test cells received a spike which consisted of 39 grams of benzene, 37 grams of ethylbenzene, and 32 grams of toluene. Glass vials sealed with gelatin were used to distribute the compounds throughout the top layer of the first one-foot lift of refuse in these two cells. This provided a known quantity of material to follow through the history of the project and three individual compounds whose peaks and GC retention times are well known. A complete report will be available in the Spring of 1986 which will contain all of the GC data developed over the five-year project.

A landfill gas may contain a large number of trace impurities, so some seventeen compounds plus the three included in the spikes were sought in the GC/MS analysis. These compounds were outlined earlier and can be seen in Table 3. A brief discussion of the sources of trace landfill gas impurities is in order before the data developed here may be appreciated. First, it must be understood that any compound that may be converted to a gas may be found in landfill gas. So a large number of possible compounds exist. We shall not take the time here to describe the ways that a compound could be converted to a gas in the landfill setting and then be found as part of the landfill gas, but there are many possible ways. Any of the products used by man may in theory be converted to the gaseous state. Some compounds are by nature volatile, while others may be partially decomposed to release gaseous compounds. Some compounds are released by corrosion of the container in the landfill setting. Many pressure-can gases are released in this manner. Since modern man uses such a variety of manufactured and natural products, it is not surprising that the refuse which is cast off contains such a variety of chemical compounds.

Target volatile organic compounds selected for analysis here represent a cross section of potential problem-causing compounds. Some may cause corrosion of the gas burner and others may produce toxic end products when burned. Some are thought to be carcinogenic or mutagenic and may cause a health threat to landfill gas recovery personnel. All of these problems are controlled by the concentration of the specific impurity in the gas stream. Simply stated, the effect is concentration-dependent. Therefore, it is necessary to know the concentrations of important compounds in the gas. These target compounds are either important themselves, or they represent groups of compounds which are important in overall evaluation of landfill gas recovery and use.

Table 8 contains the blanks used in these analyses and should be discussed first. All gas concentrations have been maintained in units of mass or mass per volume for ease of comparison throughout the discussion. Appendix A contains all results in terms of both mg/m^3 and ppm. The column designated "Blank Trap" represents the values determined from the laboratory equipment itself. ND values denote that less than five nanograms were detected by the GC/MS. Notice that only the levels of benzene and methylene chloride (dichloromethane) were above this value. Benzene and methylene chloride are used so routinely in the laboratory that it is hard to totally erase their presence with the low detection limits of the high resolution GC/MS equipment. So 6.7 ng benzene and 20 ng dichloromethane (methylene chloride) at STP, 25°C, were found by the GC/MS. Other target compounds were less than 5 nanograms and were reported as ND.

The column designated "Air Blank" represents the air values in the high bay area where the test cells are located. Notice that where only two reportable concentrations were in the laboratory blank, now there are eight reportable compounds which were present in the test cell area air. These were in order of concentration from highest to lowest: xylene, propylbenzene, ethyl benzene, toluene, hexane, benzene, methylene chloride, and tetrachloroethylene. These compounds were to be expected in the area because of the research activities in the laboratory high bay setting and the gases which are vented to the area when gas value measurements are taken on each test cell. This venting has occurred over a five-year period.

The difference between a relatively clean laboratory setting and a field-type area is readily apparent. The high bay area has served many experiments which involved painting, construction, fabrication, grinding of refuse, storage of refuse samples, leachate sampling, etc. These concentrations of impurities were expected. Xylene was the highest. It is a frequent constituent of paints and should be expected in all landfill gas and locations near landfills. Second highest were the benzenes, propylbenzene, and ethylbenzene. They are widely used compounds and were expected. Toluene is a paint solvent which is widely used. Next in order of concentration were hexane, 1.14 mg/m^3; benzene, 0.67 mg/m^3; and methylene chloride, 0.431 mg/m^3. These have many possible sources. They are all laboratory solvents that have been used at some time in the Center Hill laboratories. They are also constituents of the compounds in the refuse, so again they should be expected in

TABLE 8. TRACE VOC CONCENTRATIONS IN BLANKS

COMPOUND	BLANK TRAP ng	AIR BLANK 6/20/85 mg/m^3 at 25°C
Pentane	ND	ND
Tetrahydrofuran	ND	ND
Freon	ND	ND
Benzene	6.7	0.675
Dichloromethane	20	0.435
Hexane	ND	1.14
Toluene	ND	3.78
1,1-Dichloroethylene	ND	ND
1,2-Dichloroethylene	ND	ND
1,1-Dichloroethane	ND	ND
o,m,p-Xylenes	ND	18.3
Ethylbenzene	ND	8.37
Chlorobenzene	ND	ND
Iso-octane	ND	ND
Isopropylbenzene	ND	ND
Propylbenzene	ND	8.01
Carbon Disulfide	ND	0.503
Naphthalene	ND	ND
Nonane	ND	ND
Trichloroethylene	ND	ND
1,1,2-Trichloroethane	ND	ND
Tetrachloroethylene	ND	0.039

ND Not detected, <5 ng in sample trap

landfill gas. The compound found in the least concentration, tetrachloroethylene at 0.04 mg/m^3, is widely used in dry cleaning operations and may be expected in the refuse and gas from refuse.

Tables 9 and 10 contain the concentrations of impurities found in the gas from the test cells. Both tables list the VOCs in order of increasing molecular weight. It should be noted that three additional VOCs, tetrahydrofuran, freon, and carbon disulfide, were found in relatively high levels in many of the samples and therefore have been included.

TABLE 9. TRACE VOC CONCENTRATIONS, mg/m^3 at 25°C

LYSIMETER	21*†	21†	22	22	23*
SAMPLE DATE	5/22/85	6/20/85	6/20/85	7/01/85	5/22/85
	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3
COMPOUND					
Pentane	ND	6.42	0.20	1.33	P
Tetrahydrofuran	ND	ND	0.406	ND	ND
Freon	ND	67.7	0.203	13.3	ND
Benzene	12.2	12.1	1.02	1.05	0.40
Dichloromethane	0.05	27.7	0.71	54.1	0.017
Hexane	P	101	1.02	26.4	P
Toluene	11.2	128	20.3	21.1	3.62
1,1-Dichloroethylene	0.04	ND	ND	ND	0.032
1,2-Dichloroethylene	0.99	0.54	1.31	1.85	1.27
1,1-Dichloroethylene	ND	ND	ND	ND	ND
o,m,p-Xylenes	13.3	175	112	118	12.2
Ethylbenzene	8.78	105	24.4	25.1	4.58
Chlorobenzene	ND	ND	ND	ND	ND
Iso-octane	ND	ND	ND	ND	ND
Isopropylbenzene	ND	ND	ND	ND	ND
Propylbenzene	P	33.7	8.11	11.8	ND
Carbon Disulfide	ND	67.7	0.965	128	0.018
Naphthalene	ND	ND	ND	ND	ND
Nonane	ND	ND	ND	ND	ND
Trichloroethylene	0.149	0.506	0.193	0.185	0.389
1,1,2-Trichloroethane	ND	ND	ND	ND	ND
Tetrachloroethylene	0.292	ND	ND	0.146	0.155

* High sample volume, results tend to be low
P Identified, but not quantified
ND Not detected, <5 ng in sample trap
† Waste spiked with benzene, toluene, and ethylbenzene

Note that all of the samples from the test cells contained the three compounds used in the spike: benzene, ethylbenzene, and toluene. Concentrations of benzene were about one fourth of that in the spiked cell. Toluene concentrations exceeded one of the spiked cell concentrations in some of the samples. Ethylbenzene also exceeded the spike cell levels in some of the samples. This is not surprising when the mass of material is taken into consideration. Refuse mass was about 1,000 pounds in each test cell. The mass of the spike compounds was only a few grams. The total mass of the three spike compounds was about one quarter pound. So the ratio of refuse mass to

TABLE 10. TRACE VOC CONCENTRATIONS, mg/m^3 at 25°C

LYSIMETER SAMPLE DATE COMPOUND	33 6/20/85 mg/m^3	33 7/01/85 mg/m^3	35 6/20/85 mg/m^3	35 (duplicate) 6/20/85 mg/m^3
Pentane	ND	ND	2.13	0.90
Tetrahydrofuran	0.653	0.626	0.408	1.08
Freon	1.08	31.3	ND	9.71
Benzene	1.30	0.725	0.821	1.18
Dichloromethane	2.71	115	0.321	38.4
Hexane	1.08	30.5	2.00	10.7
Toluene	33.5	20.8	48.00	65.2
1,1-Dichloroethylene	ND	ND	ND	ND
1,2-Dichloroethylene	ND	0.061	0.651	1.50
1,1-Dichloroethylene	ND	ND	ND	ND
o,m,p-Xylenes	249	9.14	120	513
Ethylbenzene	68.3	25.6	97.1	138
Chlorobenzene	ND	ND	ND	ND
Iso-octane	ND	ND	ND	ND
Isopropylbenzene	ND	ND	ND	ND
Propylbenzene	ND	3.66	3.00	5.34
Carbon Disulfide	8.02	112	10.8	0.142
Naphthalene	ND	ND	ND	ND
Nonane	ND	ND	ND	ND
Trichloroethylene	ND	0.165	0.13	0.171
1,1,2-Trichloroethane	ND	ND	ND	ND
Tetrachloroethylene	ND	0.032	ND	ND

* High sample volume, results tend to be low
P Identified, but not quantified
ND Not detected, <5 ng in sample trap

spike mass was greater than 4000:1. Only seven of the original twenty target compounds were not found in any of the samples taken. These compounds were 1,1-dichloroethane, chlorobenzene, iso-octane, isopropylbenzene, naphthalene, nonane, and 1,1,2-trichloroethane. Most of these compounds would be used in much higher quantities by industry than they would be used by the average family. So again, their absence here is not surprising.

Of those compounds found, concentrations were higher than has been reported in the literature. The primary reason for this was a controlled setting in the lysimeter. Most literature data comes from sites where the

gas release cannot be controlled, such as large landfills or hazardous waste sites. The landfill is exposed to atmospheric changes. Ambient air moves to and from the landfill as pressure increases or decreases. This causes dilution and dispersion of the gas within the landfill. The lysimeter gas was taken directly from the test cell piping. There was no dilution of the sample by ambient air. The concentrations reflect different release patterns over time. This was to be expected due to the large number of complex biological, chemical, and physical phenomena involved in the release of these compounds.

Figures 4 through 9 have the compounds grouped according to relative concentrations found in the gas. It should be emphasized here that none of the VOC analyses was performed on recycle cells. Each of these cells was watered once each month with 31 liters of Cincinnati tap water. None of these cells received municipal sewage sludge, which contains many of these same compounds. So the source of these compounds was either from the water or the refuse. Concentrations are such that they appear to be mainly from the decomposing refuse.

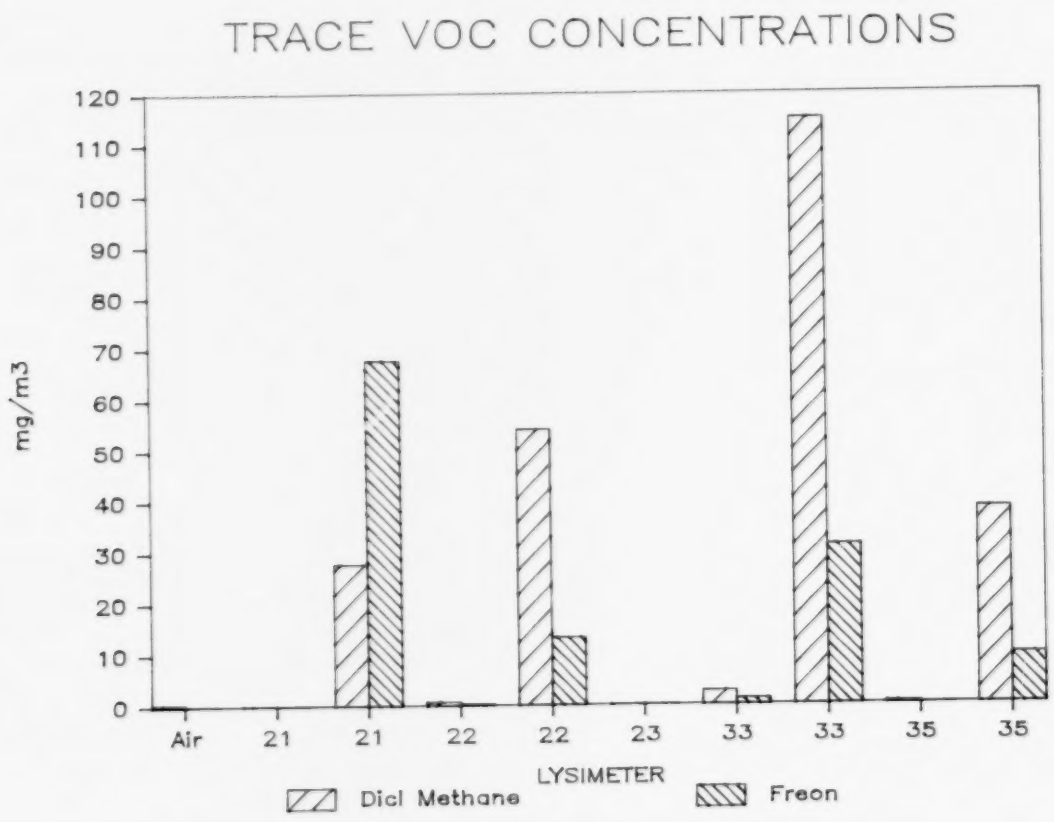

Figure 4. Dichloromethane and freon concentrations

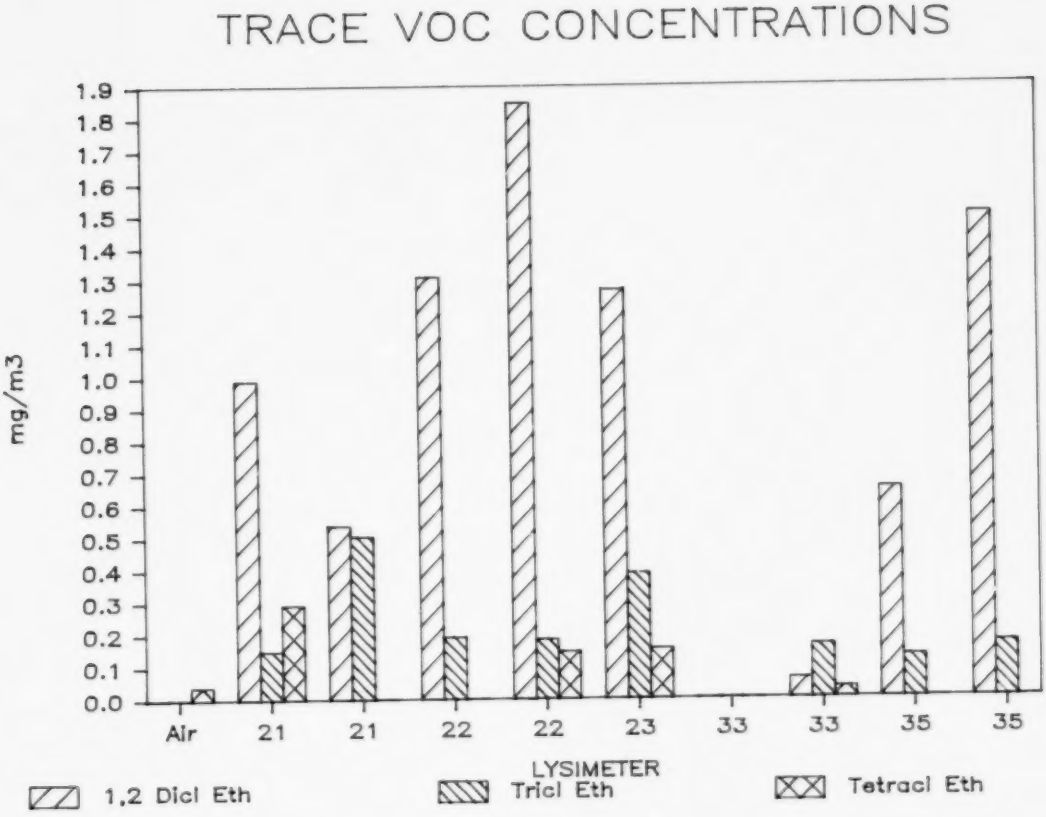

Figure 5. 1,2-Dichloroethylene, trichloroethylene, and tetrachloroethylene concentrations

Dichloromethane and freon (Figure 4) are widely used in the manufacture of drugs and drug products, household appliances, electronic applicances, and a host of other uses where metal must be cleaned or degreased. Both of these compounds require high temperatures for complete destruction to release the chlorine as hydrogen chloride (HCl) or elemental chlorine (Cl_2). If burned at lower than adequate temperatures for complete decomposition, toxic products may result. Samples from test cells 21, 22, 33, and 35 had significant concentrations of these two chlorinated solvents.

Dichloroethylene, trichloroethylene, and tetrachloroethylene (Figure 5) are more heavily chlorinated solvents that are used widely in cleaning industrial processing equipment and dry cleaning operations. The same comments apply here as for the freon and methylene chloride compounds. If they are not burned at the proper temperature, toxic end products may result. Levels of these compounds were much lower than the freon and methylene chloride, but their concentrations were significant. They were found to some degree in all of the samples from the test cells except for one of the samples from test cell 33. Test cell 22 had the highest individual concentration for one of these compounds, which approached 2.0 mg/m^3.

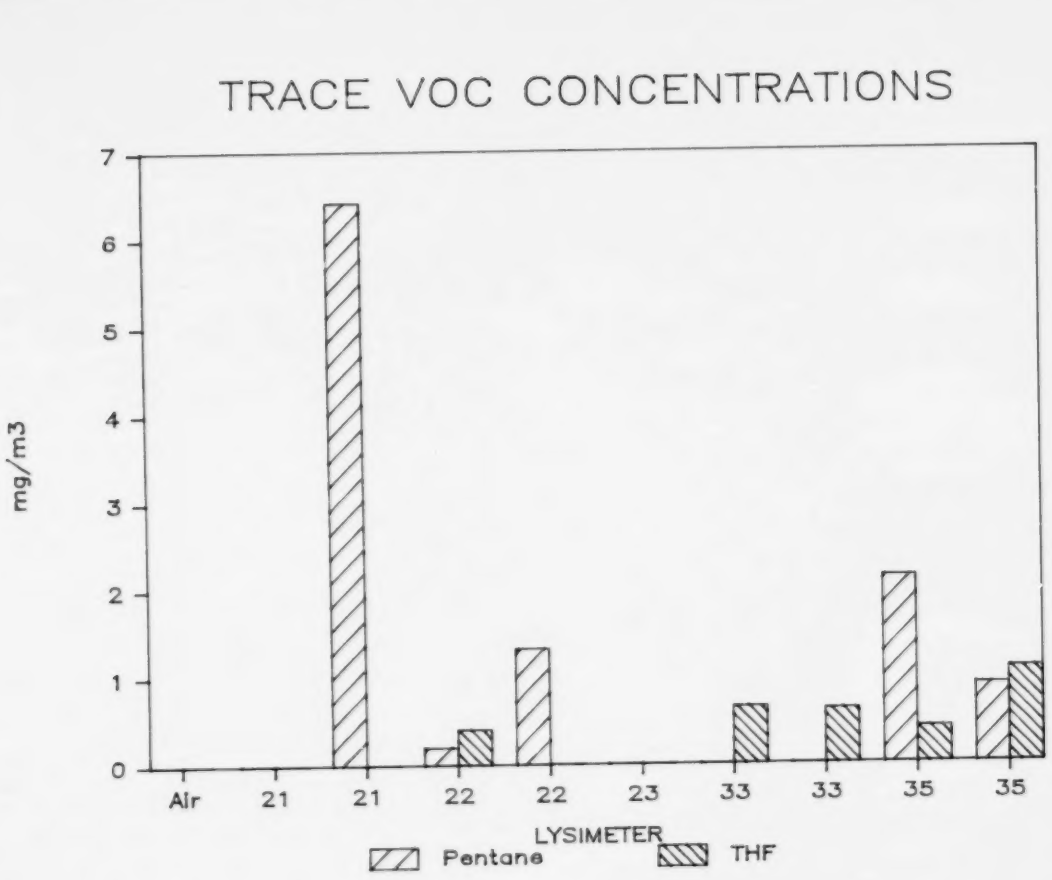

Figure 6. Pentane and tetrahydrofuran concentrations

Pentane and tetrahydrofuran (Figure 6) are two widely used solvents which appeared in all but two of the samples. These compounds are extremely flammable and are widely used in the manufacture of products that are in the home. For example, the pentane is widely used in lighter fluids and portable stove fuels. Tetrahydrofuran is widely used as a solvent in printing inks. Fifty-one percent of the refuse mass was paper. Much of it was printed newspaper. The highest concentration for the pentane was 6.42 mg/m^3 and the highest concentration for the THF was 1.08 mg/m^3.

Hexane and propylbenzene (Figure 7) are two more widely used solvents for routine household products. Hexane was found at 101 mg/m^3 in the highest sample, and propylbenzene was found at 33.7 mg/m^3 in test cell 21 for the high value. These compounds were found in seven of the nine samples.

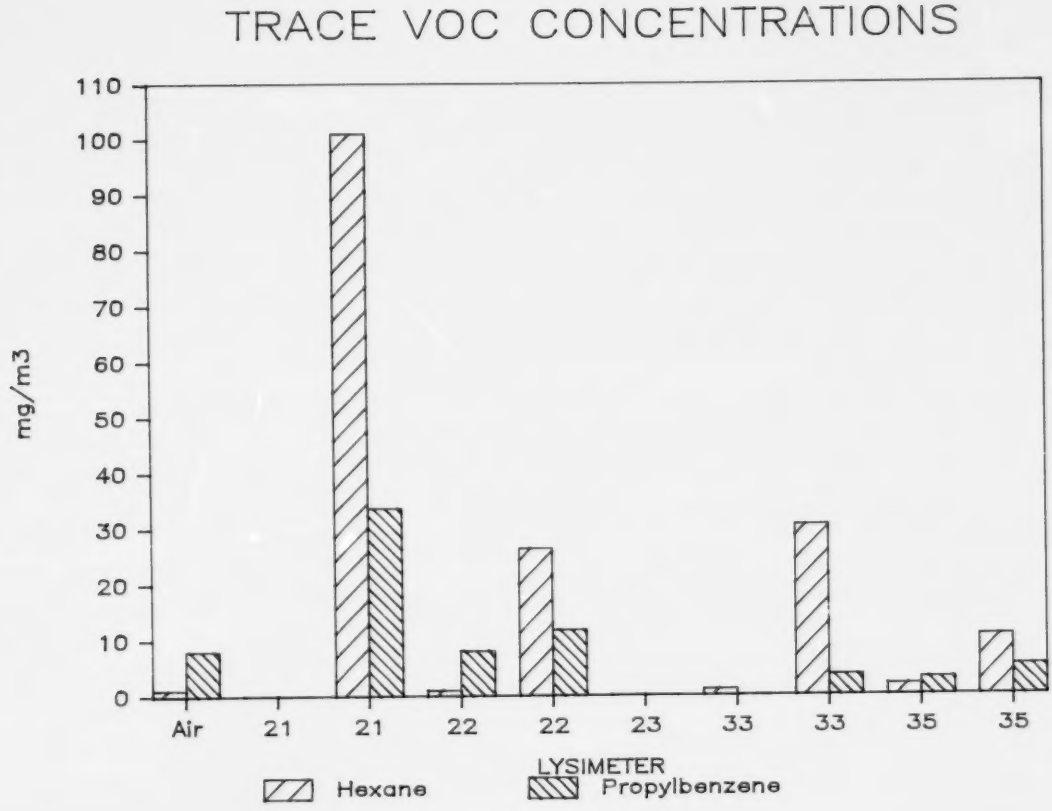

Figure 7. Hexane and propylbenzene concentrations

Benzene, toluene, and ethylbenzene (Figure 8) are three very common solvents used by just about every process industry in the manufacture of household products. Benzene is a starter compound for organic compound synthesis and therefore is widely used in paints and inks. Ethylbenzene is used in paint manufacture and many coating materials. These compounds were found in all of the nine test cell samples. Highest concentrations were in decreasing order: toluene, 128 mg/m^3; ethylbenzene, 105 mg/m^3, and benzene, 12.2 mg/m^3, respectively.

Xylenes and carbon disulfide (Figure 9) are two solvents which were found in the highest concentrations of any of the VOCs determined. These two are widely used in paints and plastic manufacture, so it was not surprising to find these in high concentrations. The xylenes were highest at 512 mg/m^3 in test cell 35. Carbon disulfide was highest in test cell 22 at 128 mg/m^3. One of these two was found in every sample from the test cells. Since carbon disulfide contains sulfur, it may cause corrosion when burned. Possible end products are sulfur dioxide, SO_2, and sulfuric acid, H_2SO_4. Both of these compounds are very corrosive.

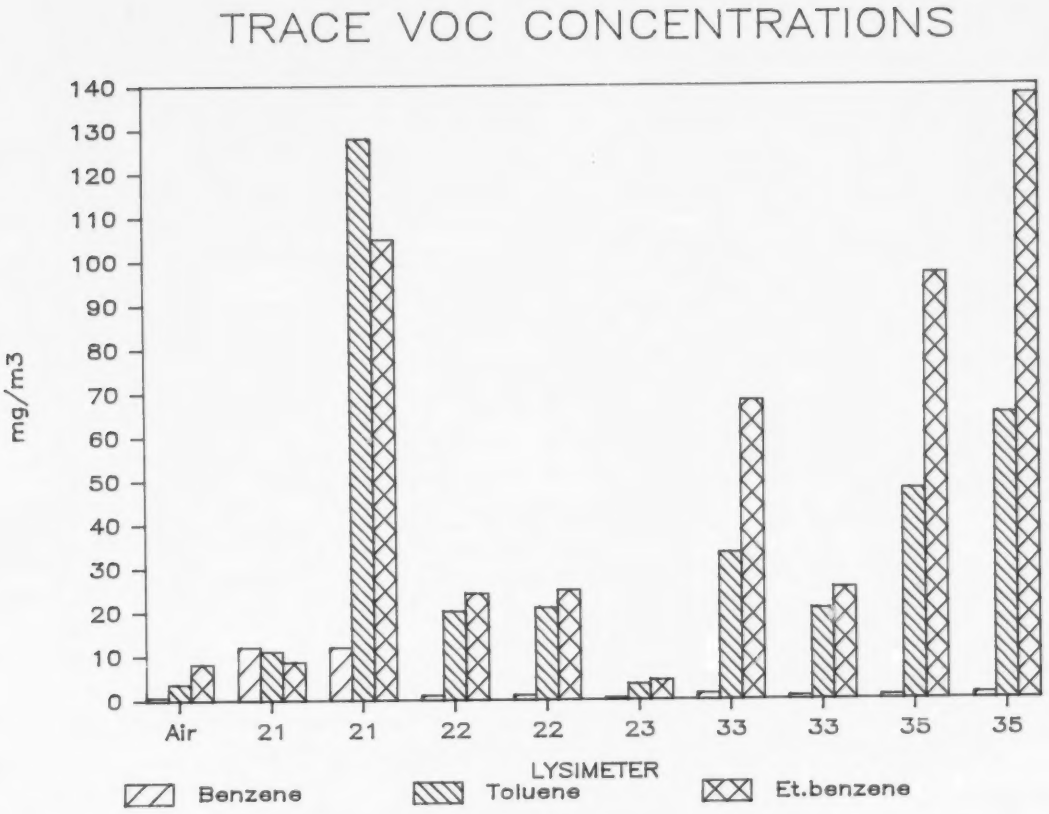

Figure 8. Benzene, toluene, and ethylbenzene concentrations

Analysis of the VOC data indicate that many of these trace organic compounds which may pose a threat to processors and users of landfill gas are in the gas in various concentrations. Many of the concentrations observed here are much higher than previously reported. This suggests that additional trace volatile organic compound monitoring should be carried out. This could be done in landfill studies similar to this one and at gas recovery facilities. Concentrations observed here should be evaluated as to their health effects in processing and in use of the gas.

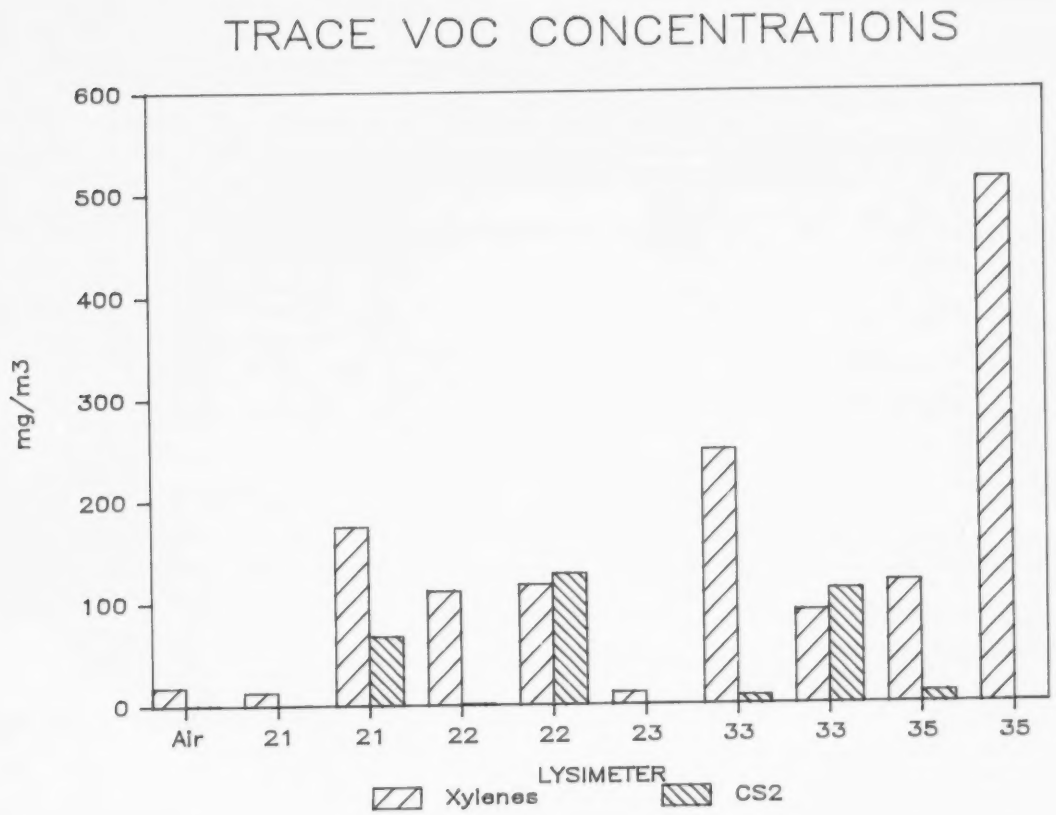

Figure 9. Xylenes and carbon disulfide concentrations

MICROBIOLOGY

In order to determine which organisms were actively stabilizing the waste, the refuse from six of the test cells was examined for the presence of aerobic and anaerobic bacteria, fungi, total coliforms, fecal coliforms, fecal streptococci, gram negative rods and clostridia. Since the refuse was saturated prior to removal to eliminate explosive levels of methane, the refuse moisture contents were relatively high (Table 11). Therefore, all microbiological results are reported on a dry weight basis.

The majority of the analyses were performed on an initial homogenized sample that consisted of 80 grams of coarsely ground refuse and 320 ml of 0.1% peptone water. It should be emphasized that the refuse was coarsely ground and therefore was present in relatively large pieces. This resulted in a thick slurry-like sample that was difficult to work with. Unfortunately, at this sample level many of the analyses showed no microbial growth at the lowest dilutions used. These results can therefore only be reported in terms of a maximum number of organisms present. That is, results are reported as "less than" some value. When dilutions and moisture contents are taken into account these values are often rather high. Typically these

TABLE 11. Microbiological Sample Moisture Contents

SAMPLE	% MOISTURE
20T	65.5
20B	66.4
23T	63.5
23B	68.8
25T	64.3
25B	67.9
26T	73.3
26B	75.2
30T	62.6
30B	63.9
35T	72.8
35B	69.3

"maximums" ranged from 200 to 800 MPN/100 grams dry weight for the coliforms to 3,000 to 65,000 CFU/100 grams for the gram negative rods. While these possible "maximums" are often rather large, it should be kept in mind that although the number of organisms present could be as high as 65,000 CFU/100 grams, it could also be as low as 0 CFU/100 grams. The analysis simply did not allow for a more conclusive description of these organisms. Due to the nature of the homogenized sample consisting of 80 grams of sample and 320 ml of liquid, it was not possible to increase the weight of refuse use without encountering serious subsampling and analytical difficulties. For example, the solids tended to settle out very quickly and made obtaining a representative subsample nearly impossible. Also, when performing MPN determinations, the high solids tended to form a cap on the top of the tubes. In some cases this resulted in false positives on the presumptive portion of the analysis. On plate counts, the lower dilution samples tended to leave debris on the plate which could be difficult to distinguish from organism growth. Therefore, the 80-gram refuse sample was considered the maximum weight that could be reliably sampled and provide acceptable results. These problems emphasize the inadequacy of using standard water and wastewater microbiological analyses on solid waste samples. Development of microbiological methods for solid waste is clearly needed in order to obtain the most conclusive and comparable data.

Before looking at the microbiological results, it is important to point out two factors relating to the original gas enhancement study that undoubtedly had a significant although non-quantifiable impact on the microbiology of

the test cells. First, the refuse was delivered directly from city collection vehicles, and after a sort sample was analyzed, the refuse was transferred to Columbus, Ohio, where it was weighed and shredded. The grinding process involves extremely high temperatures which can and probably did destroy some of the microbial population. Since there was no microbiology on the original refuse or on the shredded refuse, there is no way to determine whether this was in fact the case. Second, the experimental landfills were loaded without a clay liner on the top of the refuse as would be found in an actual landfill situation and is commonly done in experimental landfill design. This was purposely omitted in order to concentrate on the enhancement techniques applied; however, the result to the lysimeters was the lack of a source of microorganisms available to reseed the refuse. Since some fraction of the microbial population was undoubtably destroyed in the grinding process, this lack of a source of microorganisms probably slowed the decomposition process and perhaps limited the level of organisms found in the refuse during this study. With these limitations in mind, the results obtained can be put into a workable perspective.

Clostridium Perfringens, Total Plate Counts, Fungi

The microbiological analyses can be viewed in three distinct groups. The first group (Group 1) represents the organisms found in relatively high numbers in all samples and consists of the fungi, Clostridium perfringens, and both the aerobic and anaerobic standard plate counts. The next group (Group 2) represents the organisms which were generally found in lower numbers and often not found in many of the samples. Organisms in this group are the gram negative rods, total and fecal coliforms, fecal streptococci, and the clostridia as determined by tryptone sulfite cycloserine agar plate counts. The last group (Group 3) consists solely of the methane bacteria.

Figure 10 graphically depicts the result of the first group: Clostridium perfringens, the standard plate counts, and the fungi. Actual results for these analyses can be seen in Table 12.

Cell 20 was considered a control cell throughout the five-year study, receiving low infiltration only. Clostridium perfringens and anaerobic organism levels decreased from the top sample to the bottle sample, while fungi and aerobic organism levels stayed the same. Clostridium perfringens seemed to predominate the sample from the top of the cell at 3.45×10^8 MPN/100 grams. All of the Group 1 organism types were present at similar levels in the bottom sample, ranging from the anaerobic plate counts at 2.34×10^5 CPU/100 grams to the aerobic plate counts at 1.53×10^6 CFU/100 grams.

Cell 23 received only high infiltration throughout the study. The two types of organisms that decreased in cell 20 as well as the aerobic plate count levels increased from the top to the bottom sample in this cell. As in cell 20, fungi levels were essentially the same in both top and bottom samples. Relative levels of organisms were not too different between the bottom sample of cell 20 and the top sample from cell 23. Clostridium perfringens was the most prevalent in both the top and bottom samples in this cell with

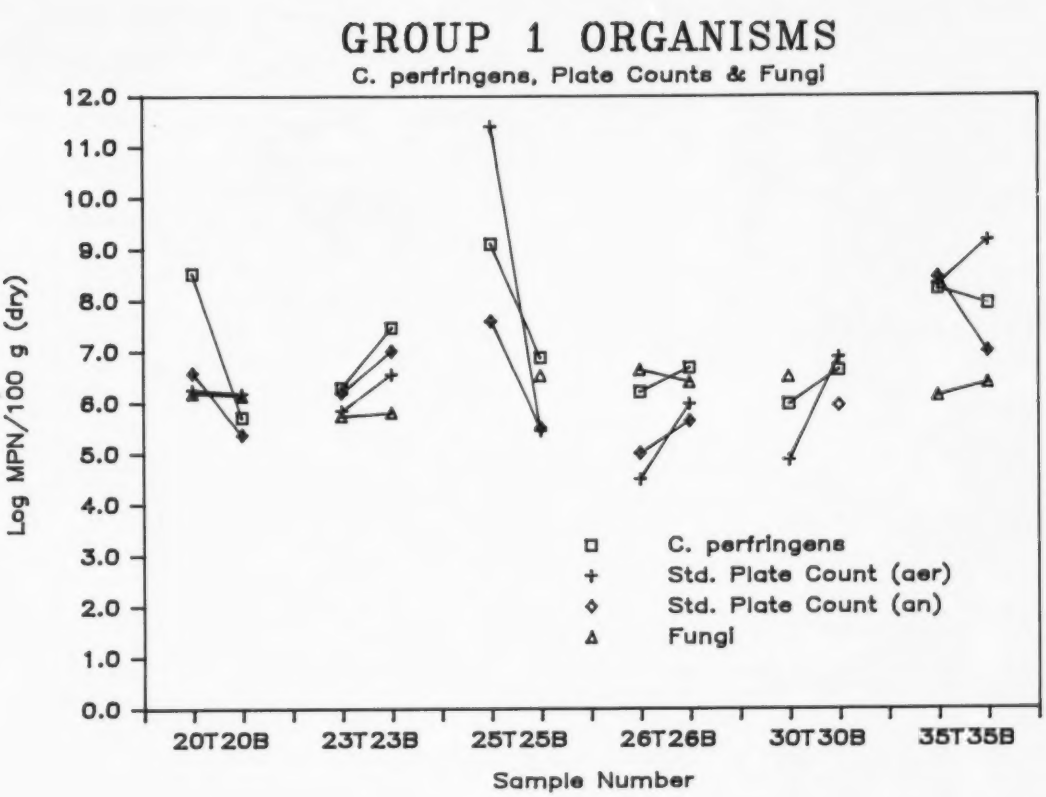

Figure 10. Fungi and Clostridium perfringens total plate count (aerobic and anaerobic)

levels of 1.95×10^6 and 2.38×10^7, respectively.

Cell 25 had the most dramatic change in organism levels from the top sample to the bottom sample. The number of aerobic and facultative anaerobic organisms as indicated by the aerobic standard plate count performed on the top sample from cell 25 was the highest count recorded in any of the samples analyzed. The Clostridium perfringens counts and anaerobic standard plate counts were also higher than most other samples, but not as significantly different as the aerobic plate counts. This is undoubtedly due to the addition of anaerobically digested sludge at the time of cell reloading in February 1983. This would not only introduce large numbers of organisms to the cell, but would also provide excellent conditions for organism growth and survival. The fungi levels in this same sample were very low. In fact, there was no evidence of fungi at the lowest sample dilutions tested. This would be expected since the organisms introduced from the sludge would be those generally found in human or other animal intestinal tracts. Fungi are probably introduced to the municipal refuse from soil, garden trimmings, or

TABLE 12. GROUP 1 MICROORGANISMS (STANDARD PLATE COUNTS, CLOSTRIDIUM PERFRINGENS, FUNGI)

SAMPLE	STANDARD PLATE COUNT (CFU/100 g dry)		CLOSTRIDIUM PERFRINGENS (MPN/100 g dry)	FUNGI (CFU/100 g dry)
	Aerobic	Anaerobic		
20T	1.80×10^{6}	3.88×10^{6}	3.45×10^{8}	1.57×10^{6}
20B	1.53×10^{6}	2.34×10^{5}	5.22×10^{5}	1.38×10^{6}
23T	6.98×10^{5}	1.60×10^{6}	1.95×10^{6}	5.58×10^{5}
23B	3.66×10^{6}	1.05×10^{7}	2.98×10^{7}	6.47×10^{5}
25T	$>2.60 \times 10^{11}$	3.98×10^{7}	1.28×10^{9}	$<8.64 \times 10^{3}$
25B	2.86×10^{5}	3.17×10^{5}	7.62×10^{6}	3.43×10^{6}
26T	3.13×10^{4}	1.01×10^{5}	1.63×10^{6}	4.41×10^{6}
26B	9.66×10^{5}	4.41×10^{5}	4.86×10^{6}	2.53×10^{6}
30T	7.44×10^{4}	$<1.36 \times 10^{4}$	9.47×10^{5}	3.25×10^{6}
30B	7.85×10^{6}	8.83×10^{5}	4.38×10^{6}	$<5.48 \times 10^{3}$
35T	2.01×10^{8}	2.78×10^{8}	1.68×10^{8}	1.35×10^{6}
35B	1.47×10^{9}	9.90×10^{6}	8.61×10^{7}	2.42×10^{6}

refuse that has been in contact with soil or a similar favorable medium for fungi. The bottom sample from cell 25 showed all Group 1 organisms present in levels similar to both cell 20 and cell 23, including the fungi, which showed the second highest level of all organisms tested in this sample.

Cell 26 organism levels for Clostridium perfringens, aerobic and anaerobic plate counts behaved similarly to those seen in cell 23. That is, levels of these organisms increased from the top sample to the bottom sample. However, organism levels ranged from one to two orders of magnitude lower than in cell 23. In cell 23 the fungi were found at the lowest levels in both the top and bottom samples. Conversely, in cell 26 the fungi were found in the highest levels of the Group 1 organisms. This cell received high infiltration, as did cell 23, but this infiltration was received in the form of leachate recycle. Cell 26 also received a calcium carbonate buffer addition at the time of original cell loading. The relative levels of the fungi with respect to the bacteria in these two cells may reflect the pH of the refuse within each cell. That is, the leachate recycling in cell 26 would tend to lower the pH, making conditions less favorable for bacterial growth and survival. The fungi would continue to grow in the lower pH environment. Calcium carbonate buffer was added to cell 26 to prevent such a decrease in pH levels; however, this data would tend to suggest that the buffer addition was not capable of reversing the effect of leachate recycling on refuse pH. The leachate recycling would also increase the level of toxics (volatile

acids) which would inhibit methane production. Cell 23 infiltration water was composed of Cincinnati tap water, therefore the pH of the refuse was probably higher and the level of volatile acids was probably lower. Unfortunately, the pH of these samples was not measured. However, the levels of volatile acids in the leachate clearly demonstrates the buildup of these toxics in the leachate recycle cells (Table 13).

TABLE 13. MEAN LEACHATE VOLATILE ACIDS, 1984

TEST CELL		VOLATILE ACIDS (mg/l)	TEST CELL		VOLATILE ACIDS (mg/l)
20		11,600	28	L. Recycle	18,500
21		11,800	29	L. Recycle	19,800
22		7,660	30	L. Recycle	21,700
23		8,060	31	L. Recycle	21,300
24	L. Recycle	24,100	32		1,240
25	L. Recycle	18,900	33		1,090
26	L. Recycle	25,600	34		7,441
27	L. Recycle	15,100	35		10,300

Data from "Demonstration of Landfill Gas Enhancement Techniques in Landfill Simulators"

The effects of a buildup of volatile acids can be estimated by comparing the relative levels of methane produced from each cell. At a low pH with high levels of volatile acids, the methane bacteria would have difficulty surviving; therefore, methane levels would be expected to be lower. This is in fact the case as can be seen in Table 14, which shows the cumulative methane gas production rates for 1984, the final year of the study. Cells 24 through 31 were all leachate recycle cells, and these cells clearly have the highest levels of volatile acids. Cells 25, 27, and 29, which all received sludge as an enhancement technique at the time of cell reloading, had the highest methane levels of all of the cells. Apparently sufficient microorganisms were re-seeded in these cells to allow conversion of the high concentrations of volatile acids to methane. However, the other five leachate recycle cells were the lowest methane gas producers.

The increase in organism levels from the top sample to the bottom sample may reflect conditions that were less affected by the leachate recycle and therefore more favorable to bacterial survival in the bottom of the cell. This could be the result of a natural layering effect of the leachate. That is, the majority of the toxics would tend to stay in the upper portions of the refuse so the effects of the volatile acid concentrations would decrease as sample depth increased.

TABLE 14. 1984 CUMULATIVE GAS PRODUCTION RATES

TEST CELL	GAS PRODUCTION (l/kg/yr)	TEST CELL	GAS PRODUCTION (l/kg/yr)
20	0.22	28	0.08
21	0.57	29	11.60
22	0.41	30	0.18
23	2.20	31	0.09
24	0.19	32	8.42
25	11.40	33	5.43
26	0.21	34	0.20
27	11.30	35	4.32

Data from "Demonstration of Landfill Gas Enhancement Techniques in Landfill Simulators"

Cell 30 organism levels were similar to cell 26. This is not unexpected since cell 30 received the same enhancement techniques as cell 26, with the addition of the nutrient supplement, ammonium phosphate ($[NH_4]_2PO_4$), at the time of original loading, and the temperature of the cell was increased at the time of cell reloading. The fungi were the most prevalent organisms in the top sample from this cell, which may again reflect the low pH and high volatile acid level in the refuse resulting from from leachate recycle. There were no anaerobic bacteria found at the lowest dilutions used from this sample. In the bottom sample the anaerobic plate counts were found to be 8.83×10^5 CFU/100 grams, and no fungi were found at the lowest sample dilutions analyzed. An additional interesting difference between the top and bottom samples was the increase in the aerobic plate counts from the top sample (7.44×10^4 CFU/100 grams) to the bottom sample (8.83×10^5 CFU/100 grams). The increase in microbial levels from the top sample to the bottom sample may again reflect the layering out of the toxics introduced to the cell by leachate recycle. Since the fungi levels were very low, it may also suggest that conditions were not only less hostile for the bacteria, but actually favored bacterial growth. Microbial populations in the bottom of the cell would receive the minimum negative effects from the leachate recycle and would perhaps be able to respond to the nutrient/buffer addition and/or the increase in cell temperature.

Test cell 35 organism levels differed somewhat from the other five cells. Fungi levels were similar to the other cells and increased slightly from the top sample to the bottom sample. Cell 35 showed a decrease in levels from top to bottom for Clostridium perfringens and the anaerobic standard plate count, but showed an increase in aerobic counts. These counts were generally higher than counts from the other cells when comparing top samples and bottom samples. This could be the result of the nutrient addition enhancement applied to this cell both at the initial loading and at the reloading in February 1983. The addition of a nutrient slurry would ensure

that nutrient concentrations were not a limiting factor to the growth of the microorganisms.

Total and Fecal Coliforms, Fecal Streptococci, Clostridia, and Gram Negative Rods

The second group organisms: total coliforms, fecal coliforms, fecal streptococci, clostridia, and the gram negative rods can be seen in Figure 11. Actual results for these analyses can be seen in Table 15.

None of the samples had counts for all of these organisms. In fact, cell 26 did not show the presence of any of the organisms at the lowest dilutions used. Included in this group are the traditional indicator organisms which were only present in high enough levels to quantify in three of the twelve samples. The grinding process would have destroyed or removed many of the original microbes, and the environment found in the lysimeter would have

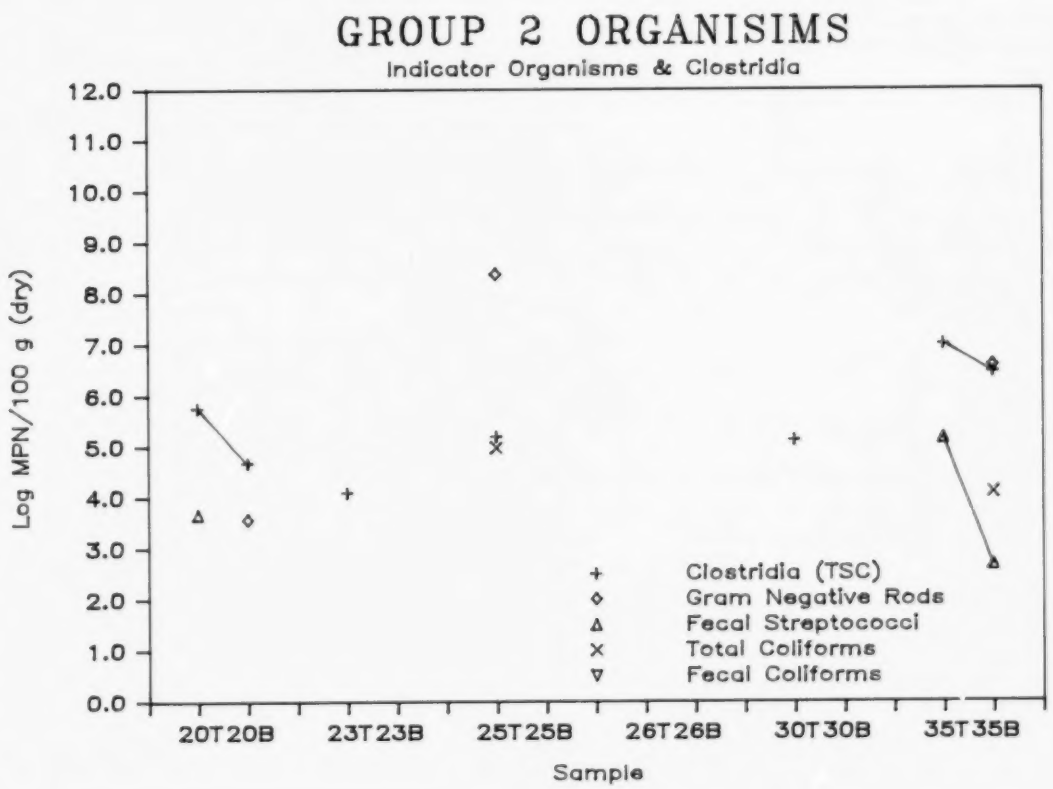

Figure 11. Fecal streptococci, Clostridia, and gram negative rods

TABLE 15. GROUP 2 MICROORGANISMS (TOTAL AND FECAL COLIFORMS, FECAL STREPTOCOCCI)

SAMPLE	TOTAL COLIFORMS (MPN/100 g)	FECAL COLIFORMS (MPN/100 g)	FECAL STREPTOCOCCI (MPN/100 g)
20T	$<2.87 \times 10^2$	$<2.87 \times 10^2$	4.74×10^3
20B	$<2.98 \times 10^2$	$<2.98 \times 10^2$	$<2.98 \times 10^2$
23T	$<5.53 \times 10^2$	$<5.53 \times 10^2$	$<5.53 \times 10^2$
23B	$<6.47 \times 10^2$	$<6.47 \times 10^2$	$<6.47 \times 10^2$
25T	9.57×10^4	$<7.98 \times 10^2$	$<7.98 \times 10^2$
25B	$<6.34 \times 10^2$	$<6.34 \times 10^2$	$<6.34 \times 10^2$
26T	$<5.98 \times 10^2$	$<5.98 \times 10^2$	$<5.98 \times 10^2$
26B	$<6.46 \times 10^2$	$<6.46 \times 10^2$	$<6.46 \times 10^2$
30T	$<5.40 \times 10^2$	$<5.40 \times 10^2$	$<5.40 \times 10^2$
30B	$<5.49 \times 10^2$	$<5.49 \times 10^2$	$<5.49 \times 10^2$
35T	$<3.64 \times 10^2$	$<3.64 \times 10^2$	1.45×10^5
35B	1.26×10^4	$<3.17 \times 10^2$	4.78×10^2

been so different from the natural environment of the indicator organisms that conditions would not have been amenable to survival and growth of these populations. This is clearly demonstrated through the fecal coliform levels. None of the samples showed any indication of the presence of fecal coliforms at the lowest dilutions used. Even if some of these organisms survived the grinding process, the substrate necessary for their survival would have been exposed and decomposed relatively quickly in the lysimeter environment. It is not surprising then that no fecal coliforms were detected after five years of disposal. It was also not surprising to see which samples did have quantifiable levels of these organisms. Cell 20, the control cell; the top sample from cell 25, where the sludge was added; and cell 35, with nutrient addition, all showed the presence of the indicator organisms. This further supports the discussion on the relative levels of the Group 1 organisms.

Gram negative rods were found in the top sample from cell 25 and the bottom in cell 35. Again, these particular cells had conditions that were more favorable to the growth and survival of the gram negative rods. The Clostridia as determined by TSC were present in all cells although not every sample, except cell 26. Based on the relatively high results of the iron milk MPN for Clostridium perfringens, at least similar levels would be anticipated from the plate counts. The actual TSC plate counts are lower than the MPN results, probably because of the different sample size used for each analysis. Plate counts were done using 0.1 ml of the 20% homogenized sample. MPNs were done using from 10 ml per tube down to 10^{-5} ml. Since the blended sample was

TABLE 16. GROUP 2 MICROORGANISMS (CLOSTRIDIA, GRAM NEGATIVE RODS)

SAMPLE	CLOSTRIDIA TSC AGAR (MPN/100 g)	GRAM NEGATIVE RODS (MPN/100 g)
20T	5.93×10^5	$<7.22 \times 10^3$
20B	4.84×10^4	3.75×10^3
23T	1.26×10^4	$<1.40 \times 10^4$
23B	$<3.20 \times 10^4$	$<6.48 \times 10^4$
25T	1.60×10^5	2.40×10^8
25B	$<1.62 \times 10^4$	$<1.58 \times 10^4$
26T	$<1.51 \times 10^4$	$<1.51 \times 10^4$
26B	$<1.62 \times 10^4$	$<1.62 \times 10^4$
30T	1.35×10^5	$<1.36 \times 10^4$
30B	$<1.37 \times 10^4$	$<1.37 \times 10^4$
35T	1.03×10^7	$<9.15 \times 10^3$
35B	2.89×10^6	3.78×10^6

not truly homogeneous (the 2-1/2 inch pieces of shredded refuse were essentially intact), varying sample sizes could have a clear impact on the results. In spite of this difference, these plate counts suggest that areas of strict anaerobic conditions did exist where the strict anaerobes such as clostridia or the methane producers could survive and grow.

Methane Bacteria

A qualitative test for the presence of methane bacteria was performed by adding samples of decreasing weight from each sample level to a methanogenesis growth medium in closed test vials. The gas produced in each vial was then measured quantitatively by gas chromatograph for the percentage of carbon dioxide, oxygen, nitrogen, and methane.

The original analysis called for a 30-day incubation period for the methane bacteria but after 30 days only five of the samples showed any methane production in the sample vials. It was determined that researchers using this method often find that an incubation period of up to 90 days is required for methane production. Since the 30-day results were incomplete samples were again inoculated with E. coli and incubated for an additional 60 days. After this 60 day incubation the gas in the 5 gram sample bottles was analyzed for the percentage of methane. Figure 12 indicates that the additional

incubation did, in fact, show methane production in more of the samples. All samples with the exception of the top sample from cell 30 and the bottom sample from cell 35 showed some level of methane production after the longer incubation period.

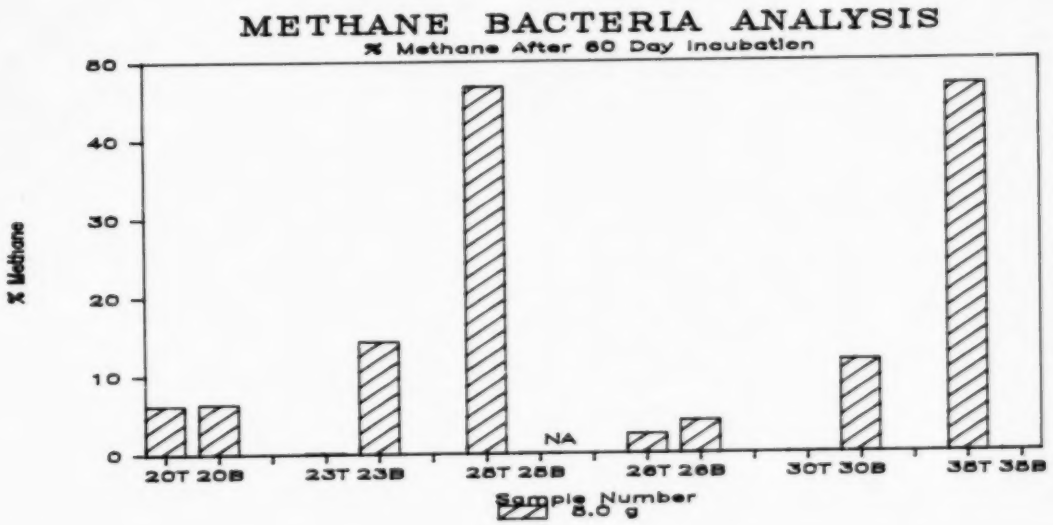

Figure 12. Methane bacteria after 60-day incubation

The absence of methane in the gas generally indicates the absence of methane-forming bacteria in the samples. Based on the 60 day incubation it is difficult to say whether the methane bacteria are truly absent from the samples or if a 90 day incubation, had it been possible within the time constraints of this project, might have indicated methane production in these samples.

Absolute percentages of methane when present varied from sample to sample. This variation may be due to many factors which were either not measured or were not measurable. For example, the amount of substrate available to the bacteria in the small microbiological samples taken may have been limiting to the bacteria. The key point to be obtained from this data is that the methane bacteria were present in each of the cells tested.

EVALUATION OF MSW IN TEST CELLS

The refuse had been ground before placing it in the lysimeters; therefore, the refuse was well mixed in the cells. No layering nor pockets of materials were noted. Some recognizable items such as coins (pennies) were found to be protected from attack. This protection was provided by paper and plastic items surrounding the coins.

Very little to no settling had occurred in the test cells over the five-year period. It appeared that any settling that did occur could be attributted to differences in the amount of moisture added to the cells. The more fresh water added to the cell, the greater the decomposition and settling. Biological decomposition seemed to be inhibited and there was less settlement in the cells where the leachate was recycled. Since water was added to all of the cells to prevent methane ignition when the cells were opened and since the effect this saturation had on settlement was unknown no firm conclusions could be drawn concerning settlement

Analysis of Waste Materials

Although the refuse was ground before placement into the test cells, many items survived this process and were able to be identified. These artifacts were physically examined, photographed, and noted as to condition. These artifacts documented the resistance to biological attack of plastic, paper, rubber, dyes, synthetic fabrics, bulk metal, plated metal, stainless steel, wood, glass, stone, and combinations of these materials.

Other items which are readily biodegradable when exposed to attack were protected from biological activity. These items were noted in several of the test cells. Bits of cheese, corn kernels, corn cobs, bread, green twigs, grass, and orange peels, which should be readily biodegradable, were protected to a small extent by plastic and paper surrounding them. A few disposable diapers survived the grinder, some with fecal matter in them. The odor upon opening the cells was fairly strong. Leachate recycle cells had a different odor than non-recycle cells. Many labels, newspapers, and book pages showed evidence of some attack, but within the same cell some were found to be easily read. Some clothing materials were still strong, while others had weakened from biodegradation. Metal objects were under varying degrees of attack. Visible attack on some copper pennies was noted. Pennies were found with copper sulfide deposits and copper sulfate deposits. Even though the refuse was ground and thoroughly mixed, there was evidence of protection of some items. In the five-year period, decomposition was evident but slow. Most of the 800 pounds of refuse originally placed in the cells was still evident.

REFERENCES

1. Stamm, J., G. Vogt, and J. Walsh. "Demonstration of Landfill Gas Enhancement Techniques in Landfill Simulators", Report No. GRI-85/0116, Final report for Gas Research Institute, Chicago, Illinois (May, 1985), 164 pp.

2. Kinman, R.N., J. Rickabaugh, W.G. Vogt, and J.J. Walsh. "Demonstration of Landfill Gas Enhancement Technique in Landfill Simulators". Final report for Department of Energy, February 1982.

BIBLIOGRAPHY

Bordner, R., J. Winter, and P.V. Scarpino. Microbiological Methods for Monitoring the Environment. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978.

Buchanan, R.E., and N.E. Gibbons (eds). 1974 Bergy's Manual of Determinative Bacteriology, 8th Ed.. The Williams & Wilkins Co., Baltimore, Maryland.

Donnelly, J.A. and P.V. Scarpino. Isolation, Characterization, and Identification of Microorganisms for Laboratory and Full-Scale Landfills. EPA-600/S2-84-119, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio, 1984.

Dowell, V.R., and T.M. Hawkins. Laboratory Methods in Anerobic Bacteriology. CDC Laboratory Manual, HEW Publication No. (CDC)77-8272, 1974.

Duncan, C.L. and S.M. Harmon. Clostridium Perfringens. In: Compendium of Methods for the Microbiological Examination of Foods, M.L. Speck (ed.). American Public Health Association Intersociety/Agency Committee on Microbiological Methods for Foods, 1976.

Handbook for Sampling and Sample Preservation of Water and Wastewater. EPA-600/4-82-029, EMSL, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1982.

Kinman, R.N., J. Rickabaugh, W.G. Vogt, and J.J. Walsh. "Demonstration of Landfill Gas Enhancement Technique in Landfill Simulators," In: Proceedings of the Fifth Madison Conference on Municipal and Industrial Waste. Madison, Wisconsin; September 1982.

Kinman, R.N., J. Rickabaugh, W.G. Vogt, and J.J. Walsh. "Demonstration of Landfill Gas Enhancement Technique in Landfill Simulators," In: Proceedings of the Sixth Madison Conference on Municipal and Industrial Waste. Madison, Wisconsin; September 1983.

Kinman, R.N., J. Rickabaugh, W.G. Vogt, and J.J. Walsh. "Demonstration of Landfill Gas Enhancement Technique in Landfill Simulators," In: Proceedings of the Seventh Madison Conference on Municipal and Industrial Waste. Madison, Wisconsin; September 1984.

Kinman, R.N., J. Rickabaugh, W.G. Vogt, and J.J. Walsh. "Demonstration of Landfill Gas Enhancement Technique in Landfill Simulators," In: Proceedings of the Eighth Madison Conference on Municipal and Industrial Waste. Madison, Wisconsin; September 1985.

Koch, A.L. Growth Measurement. In: Manual of Methods for General Microbiology, P. Gebhardt et al (eds.) American Society for Microbiology, Washington, D.C., 1981. pp. 179-207.

Koneman, E.W., et al. Color Atlas and Textbook of Diagnostic Microbiology. J.B. Lippincott Co., Philadelphia, Pennsylvania, 1983.

Koneman, E.W., G.D. Roberts, and S.F. Wright. Practical Laboratory Mycology, 2nd Edition. The Williams and Wilkins Co., Baltimore, Maryland, 1978.

Standard Methods for the Examination of Water and Wastewater, 14th Ed., APHA, AWWA, WPCF, 1975.

Standard Methods for the Examination of Water and Wastewater, 15th Ed. APHA, AWWA, WPCF, 1980.

Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. SW-846, U.S. Environmental Protection Agency, 1982.

Young, P.J., and A. Parker. "The Identification and Possible Environmental Impact of Trace Gases and Vapours in Landfill Gases". Waste Management and Research, Vol. 1 (1983). pp 213-226.

APPENDIX A

LOG OF LYSIMETER FINDINGS: TEST CELL 20

PHYSICAL CONDITIONS

Cell Additives (Original): Low infiltration

Cell Additives (Reloading): No change

Refuse Moisture Content (June 1985): Top, 65.5%
Bottom, 66.4%

Test Cell Artifacts:

- Belt
- Slipper
- Leather shoe
- Tire tread piece
- Magazine - decomposed, lettering legible, colors faded
- Underwear
- Sock
- Fork - stainless
- Bic pen
- Metal hook - brass
- Metal pieces
- Rubber pieces
- Rubber bands
- Plastic comb
- Metal comb
- Tooth brush
- Pen cartridge
- Hair curlers
- Plastic fork
- Perfume bottle
- Heart (jewelry)
- Credit card
- Y - plastic letter toy
- Pencil eraser
- Metal tag
- Queen of spades
- Pepper shaker - plastic
- Metal antennae
- Pearl button
- Belt
- Cheese
- Metal objects
- Whistle - plastic
- Artificial plant
- Prescription bottle
- Plastic gun
- Paint brush (for models)
- Spring - metal
- Plastic tip to mustard bottle
- Shoe belt and buckle
- Coins

LOG OF LYSIMETER FINDINGS: TEST CELL 20
Microbiology

ORGANISM ENUMERATIONS		
	Top Sample	Bottom Sample
Inches Into Refuse		
Std. Plate Count (aerobic)	1.80×10^6	1.53×10^6
Std. Plate Count (anaerobic)	3.88×10^6	2.34×10^5
Clostridium perfringens	3.45×10^8	5.22×10^5
Fungi	1.57×10^6	1.38×10^6
Total Coliforms	$<2.87 \times 10^2$	$<2.98 \times 10^2$
Fecal Coliforms	$<2.87 \times 10^2$	$<2.98 \times 10^2$
Fecal Streptococci	4.74×10^3	$<2.98 \times 10^2$
Clostridium (TSC agar)	5.93×10^5	4.84×10^4
Gram Negative Rods	$<7.22 \times 10^3$	3.75×10^3

METHANE BACTERIA ANALYSIS				
	Composition of Gas in Vials			
SAMPLE WEIGHT (Grams)	% CO_2	% O_2	% N_2	% CH_4
30 Day				
Top				
5.0	44.85	1.86	28.52	24.77
0.5	41.27	0.91	33.12	24.70
0.05	61.96	1.24	21.46	15.34
0.005	67.07	1.97	30.96	0.00
Bottom				
5.0	58.87	1.83	39.30	0.00
0.5	77.43	0.59	19.24	2.74
0.05	50.65	0.36	13.78	35.21
0.005	56.86	0.44	17.20	25.50
60 Day				
Top				
5.0	20.12	6.59	67.05	6.24
Bottom				
5.0	0.93	13.26	79.40	6.40

LOG OF LYSIMETER FINDINGS: TEST CELL 21

PHYSICAL CONDITIONS

Cell Additives (Original): Low infiltration

Cell Additives (Reloading): No change

NOTE: Cell was not opened for study during this project. This cell is currently part of a recently initiated gas inhibition study using lime or lime/fly ash injection to stop landfill gas production.

GC/MS ANALYSIS: Cell 21

Concentration, at STP, 25°C

	SAMPLE 1 5/22/85		SAMPLE 2 6/20/85	
VOLUME, ml at STP	1851		30.2	
TEMPERATURE, °C	19		19.4	
	mg/m^3	ppm	mg/m^3	ppm
Pentane	ND	ND	6.42	2.14
Tetrahydrofuran	ND	ND	ND	ND
Freon	ND	ND	67.7	13.4
Benzene	12.2	3.77	12.1	3.74
Dichloromethane	0.05	0.01	27.7	7.84
Hexane	P	P	101	28.3
Toluene	11.2	2.93	128	33.6
1,1-Dichloroethylene	0.04	0.01	ND	ND
1,2-Dichloroethylene	0.99	0.25	0.54	0.13
1,1-Dichloroethane	ND	ND	ND	ND
o,m,p-Xylenes	13.3	3.00	175	39.8
Ethylbenzene	8.78	1.99	105	23.8
Chlorobenzene	ND	ND	ND	ND
Iso-octane	ND	ND	ND	ND
Isopropylbenzene	ND	ND	ND	ND
Propylbenzene	P	P	33.7	6.76
Carbon Disulfide	ND	ND	67.7	21.4
Naphthalene	ND	ND	ND	ND
Nonane	ND	ND	ND	ND
Trichloroethylene	0.15	0.03	0.51	0.09
1,1,2-Trichloroethane	ND	ND	ND	ND
Tetrachloroethylene	0.29	0.04	ND	ND

ND: Not detected, <5 ng on sample trap
P: Present but not quantified

LOG OF LYSIMETER FINDINGS: TEST CELL 22

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration

Cell Additives (Reloading): No change

NOTE: Cell was not opened for study during this project. This cell is currently part of a recently initiated gas inhibition study using lime or lime/fly ash injection to stop landfill gas production.

GC/MS ANALYSIS: Cell 22

Concentration, at STP, 25°C

	SAMPLE 1 6/20/85		SAMPLE 2 7/01/85	
VOLUME, ml at STP	100		76.6	
TEMPERATURE, °C	19.4		26.9	
	mg/m^3	ppm	mg/m^3	ppm
Pentane	0.20	0.07	1.33	0.44
Tetrahydrofuran	0.41	0.14	ND	ND
Freon	0.20	0.04	13.3	2.63
Benzene	1.02	0.31	1.05	0.33
Dichloromethane	0.71	0.20	54.1	15.4
Hexane	1.02	0.28	26.4	7.44
Toluene	20.3	5.30	21.1	5.57
1,1-Dichloroethylene	ND	ND	ND	ND
1,2-Dichloroethylene	1.31	0.33	1.85	0.46
1,1-Dichloroethane	ND	ND	ND	ND
o,m,p-Xylenes	112	25.4	118	27.0
Ethylbenzene	24.4	5.52	25.1	5.73
Chlorobenzene	ND	ND	ND	ND
Iso-octane	ND	ND	ND	ND
Isopropylbenzene	ND	ND	ND	ND
Propylbenzene	8.11	1.63	11.8	2.39
Carbon Disulfide	0.97	0.30	128	40.3
Naphthalene	ND	ND	ND	ND
Nonane	ND	ND	ND	ND
Trichloroethylene	0.19	0.04	0.19	0.03
1,1,2-Trichloroethane	ND	ND	ND	ND
Tetrachloroethylene	ND	ND	0.15	0.02

ND: Not detected, <5 ng on sample trap
P: Present but not quantified

LOG OF LYSIMETER FINDINGS: TEST CELL 23

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration

Cell Additives (Reloading): No change

Refuse Moisture Content (June 1985): Top, 63.5%
Bottom, 68.8%

Test Cell Artifacts:

Aluminum wire
Golf ball
Handle of tooth brush
Paper wrapper - legible label
Athletic shoe
Plastic bottle - legible label
Metal cans - rusted, obvious degradation, balled up from grinding process
Legible print on paper items
Envelope - a lot of attack except where plastic protected address
Magazine pages - some print legible, colors faded and stained
Piece of rubber car tire
Slipper - obvious decomposition
Yogart lid - cardboard, shows attack
Pair of jeans - shows decomposition
Aluminum chain - no attack
Pepsi can - red and blue colors vivid
Plastic comb
Bottle cap - label legible
Piece of a thong
Pieces of plastic credit cards
Plastic bass
Cigarette lighter (plastic)
Bristle brush (plastic)
Hair curler (plastic)
Batteries
Artificial plants
Heel of shoe
Plastic disc
Artificial plant - pine
7-Up can - vivid colors
Prescription bottle
Jeans - material strong
Chain (metal) - rusted
Metal cans - various degrees of decomposition
Miracle Whip lid - legible print, paint over metal preserved it
Plastic bottle - legible print
Pencil
Coins

LOG OF LYSIMETER FINDINGS: TEST CELL 23
Microbiology

ORGANISM ENUMERATIONS		
	Top Sample	Bottom Sample
Inches Into Refuse		
Std. Plate Count (aerobic)	6.98×10^5	3.66×10^6
Std. Plate Count (anaerobic)	1.60×10^6	1.05×10^7
Clostridium perfringens	1.95×10^6	2.98×10^7
Fungi	5.58×10^5	6.47×10^5
Total Coliforms	$<5.53 \times 10^2$	$<6.47 \times 10^2$
Fecal Coliforms	$<5.53 \times 10^2$	$<6.47 \times 10^2$
Fecal Streptococci	$<5.53 \times 10^2$	$<6.47 \times 10^2$
Clostridium (TSC agar)	1.26×10^4	$<3.20 \times 10^4$
Gram Negative Rods	$<1.40 \times 10^4$	$<6.48 \times 10^4$

METHANE BACTERIA ANALYSIS Composition of Gas in Vials				
SAMPLE WEIGHT (Grams)	% CO_2	% O_2	% N_2	% CH_4
30 Day				
Top				
5.0	1.34	17.52	81.14	0.0
0.5	0.0	20.08	79.92	0.0
0.05	2.28	17.62	80.10	0.0
0.005	0.0	18.80	81.20	0.0
Bottom				
5.0	0.0	19.52	80.48	0.0
0.5	4.73	17.20	78.07	0.0
0.05	1.81	17.20	80.99	0.0
0.005	0.0	18.18	81.82	0.0
60 Day				
Top 5.0	2.04	3.81	94.11	0.04
Bottom 5.0	21.87	0.60	63.16	14.37

GC/MS ANALYSIS: Cell 23

Concentration, at STP, 25°C

	SAMPLE 1 5/22/85	
VOLUME, ml at STP	1914	
TEMPERATURE, °C	18.9	
	mg/m^3	ppm
Pentane	P	P
Tetrahydrofuran	ND	ND
Freon	ND	ND
Benzene	0.40	0.12
Dichloromethane	0.02	0.01
Hexane	P	P
Toluene	3.62	0.95
1,1-Dichloroethylene	0.03	0.01
1,2-Dichloroethylene	1.28	0.32
1,1-Dichloroethane	ND	ND
o,m,p-Xylenes	12.2	2.77
Ethylbenzene	4.58	1.04
Chlorobenzene	ND	ND
Iso-octane	ND	ND
Isopropylbenzene	ND	ND
Propylbenzene	ND	ND
Carbon Disulfide	0.02	0.01
Naphthalene	ND	ND
Nonane	ND	ND
Trichloroethylene	0.39	0.07
1,1,2-Trichloroethane	ND	ND
Tetrachloroethylene	0.16	0.02

ND: Not detected, <5 ng on sample trap
P: Present but not quantified

LOG OF LYSIMETER FINDINGS: TEST CELL 24

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, leachate recycle

Cell Additives (Reloading): No change

Refuse Moisture Content (June 1985): Top, 65.7%
Bottom, 60.7%

Test Cell Artifacts:

Batteries
Plastic bottles - print barely legible to legible
Plastic letters - to a game
Metal cans - varying degrees of degradation
Sole of a shoe (rubber)
Lipstick caps - some degradation of metal surface
Plastic credit card piece
Button - red, white, and blue colors vivid and protecting metal
Hypodermic syringe
Plastic - artificial plants, leaves
Sponge
Coffee grounds holder for coffee pot - no degradation evident
Sock - maroon color strong and material strong
Coins
Rock
Fork (stainless steel) - no attack
Crest toothpaste tube - strong color and label good
Piece of ceramic pottery dish
Bones
Hair comb
Metal key - coated with residue
Doll leg (plastic)
Ribbon - green
Bic pen
Plastic toys - army man, wheels, Batman figure
Copper metal disk
Brass screw - rusted
Brass buttons - no rust
Seeds
Hose fitting (brass) - rusted
Metal chain - sulfide stain
Aluminum metal object - no attack
Corn cob

LOG OF LYSIMETER FINDINGS: TEST CELL 25

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, leachate recycle

Cell Additives (Reloading): Sludge addition

Refuse Moisture Content (June 1985): Top, 64.3%
Bottom, 67.9%

Test Cell Artifacts:

- Inflatable plastic toy
- Plastic bottles - labels under attack, barely legible
- Belt
- Metal can top - label legible
- Sock - material under attack
- Plastic credit cards
- Plastic tooth brush
- Rubber bank
- Balloon
- Plastic plate - toy
- Rubber toy dinosaur
- Watch bank
- Artificial plants
- Lego block (plastic)
- Aluminum wire - shows attack
- Lipstick lid - rust
- Popsicle stick (wood)
- Battery
- Piece of plastic brush handle
- Plastic wrapper - label legible
- Stamp on letter - no attack on stamp, colors vivid, letter's paper shows attack
- Piece of plastic toy horn
- Coins

LOG OF LYSIMETER FINDINGS: TEST CELL 25
Microbiology

ORGANISM ENUMERATIONS	Top Sample	Bottom Sample
Inches Into Refuse		
Std. Plate Count (aerobic)	$>2.60 \times 10^{11}$	2.86×10^{5}
Std. Plate Count (anaerobic)	3.98×10^{7}	3.17×10^{5}
Clostridium perfringens	1.28×10^{9}	7.62×10^{6}
Fungi	$<8.64 \times 10^{3}$	3.43×10^{6}
Total Coliforms	9.57×10^{4}	$<6.34 \times 10^{2}$
Fecal Coliforms	$<7.98 \times 10^{2}$	$<6.34 \times 10^{2}$
Fecal Streptococci	$<7.98 \times 10^{2}$	$<6.34 \times 10^{2}$
Clostridium (TSC agar)	1.60×10^{5}	$<1.62 \times 10^{4}$
Gram Negative Rods	2.40×10^{8}	$<1.58 \times 10^{4}$

METHANE BACTERIA ANALYSIS Composition of Gas in Vials				
SAMPLE WEIGHT (Grams)	% CO_2	% O_2	% N_2	% CH_4
30 Day				
Top				
5.0	55.13	1.72	39.70	3.45
0.5	39.18	7.84	51.07	1.91
0.05	18.96	19.74	60.52	0.78
0.005	26.76	17.98	54.76	0.50
Bottom				
5.0	15.26	32.75	51.99	0.0
0.5	20.00	18.56	60.17	1.27
0.05	8.22	27.16	64.22	0.40
0.005	12.77	25.50	61.67	0.06
60 Day				
Top				
5.0	3.02	0.62	49.60	46.76
Bottom				
5.0	Not Analyzed			

LOG OF LYSIMETER FINDINGS: TEST CELL 26

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, leachate recycle, buffer addition

Cell Additives (Reloading): No change

Refuse Moisture Content (June 1985): Top, 75.3%
Bottom, 75.2%

Test Cell Artifacts:

Piece of umbrella - cloth strong, colors faded
Rubber bulb
Metal cans - rusted
Aluminum metal can - some attack, label legible
Milk carton - shows some attack, label legible
Plastic balloon wrapper - shows attack, but label legible
Rubber elephant toy
Prescription bottles (plastic) - labels legible
Cotton glove - darkened, material strong
Glasses case
Batteries
Cigarette pack (Kool) - shows attack on label
Plastic credit card
Lego block (plastic)
Plastic toy top
Plastic artificial strawberry
Artificial plant leaf
Marble
Rubber band
Piece of garden hose
Plastic doll arm
Plastic cap
Die
Plastic hair curler
Metal button - colors vivid, paint protected metal surface
Pierced earring
Cotter pin (aluminum) - no attack
Corn cob - some attack
Bones
Balloon
Wiring (copper and aluminum)
Metal (brass) - rusted
Negative film
Metal cans - various degrees of decomposition (aluminum cans hold up better)
Metal piece - rusted
Plastic bottle - paint faded, barely legible
Metal clip
Coins

LOG OF LYSIMETER FINDINGS: TEST CELL 26
Microbiology

ORGANISM ENUMERATIONS	Top Sample	Bottom Sample
Inches Into Refuse		
Std. Plate Count (aerobic)	3.13×10^4	9.66×10^5
Std. Plate Count (anaerobic)	1.01×10^5	4.41×10^5
Clostridium perfringens	1.63×10^6	4.86×10^6
Fungi	4.41×10^6	2.53×10^6
Total Coliforms	$<5.98 \times 10^2$	$<6.46 \times 10^2$
Fecal Coliforms	$<5.98 \times 10^2$	$<6.46 \times 10^2$
Fecal Streptococci	$<5.98 \times 10^2$	$<6.46 \times 10^2$
Clostridium (TSC agar)	1.03×10^7	2.89×10^6
Gram Negative Rods	$<9.15 \times 10^3$	3.78×10^6

METHANE BACTERIA ANALYSIS Composition of Gas in Vials				
SAMPLE WEIGHT (Grams)	% CO_2	% O_2	% N_2	% CH_4
30 Day				
Top				
5.0	2.98	19.08	77.94	0.0
0.5	0.0	10.66	89.34	0.0
0.05	0.0	21.33	78.67	0.0
0.005	0.0	20.14	79.86	0.0
Bottom				
5.0	0.0	18.44	81.50	0.0
0.5	3.54	17.39	79.07	0.0
0.05	0.0	20.03	79.97	0.0
0.005	3.73	16.68	79.59	0.0
60 Day				
Top				
5.0	1.74	12.43	83.41	2.42
Bottom				
5.0	3.84	10.90	81.15	4.11

LOG OF LYSIMETER FINDINGS: TEST CELL 27

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, leachate recycle, buffer addition

Cell Additives (Reloading): Sludge addition

NOTE: Cell was not opened for study during this project. This cell is currently part of a recently initiated gas inhibition study using lime or lime/fly ash injection to stop landfill gas production.

LOG OF LYSIMETER FINDINGS: TEST CELL 28

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, leachate recycle, nutrient addition

Cell Additives (Reloading): No change

Refuse Moisture Content (June 1985): Top, 54.5%
Bottom, 61.7%

Test Cell Artifacts:

- Raisin box - some attack
- Coffee tin lid - no attack
- Coin purse (rubber)
- Tire piece
- Sole of shoe
- Leather shoe
- Plastic plate
- Wood pieces
- Curlers (plastic)
- Paint brush
- Straw (plastic)
- Artificial flower (plastic)
- Metal zipper
- Metal Cans - various degrees of attack
- Rope
- Brass rod - some rust
- Glasses case
- Magazine - showed attack, but print fairly legible
- Cigar holder (plastic)
- Sock
- Cotton cloth
- Rubber tubing
- Plastic medicine bottle
- Plastic heart - bottle stop
- Light bulb base
- Rubber toy cowboy
- Knife blade
- Plastic card/calendar - legible
- Toe of shoe
- Cans (metal) - various degrees of degradation
- Paper cups - legible print
- Rubber ball
- Envelope - legible address
- Leather strap
- Coins

LOG OF LYSIMETER FINDINGS: TEST CELL 29

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, leachate recycle, nutrient addition

Cell Additives (Reloading): Sludge addition

NOTE: Cell was not opened for study during this project. This cell is currently part of a recently initiated gas inhibition study using lime or lime/fly ash injection to stop landfill gas production.

LOG OF LYSIMETER FINDINGS: TEST CELL 30

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, leachate recycle, buffer addition, nutrient addition

Cell Additives (Reloading): Temperature increase

Refuse Moisture Content (June 1985): Top, 62.6%
Bottom, 63.9%

Test Cell Artifacts:

- Glove - strong material
- Tennis hat (cotton) - strong material
- Shoe (leather) - strong material
- Metal cans - various degrees of attack - some labels legible
- Polaroid photo - faded but image legible
- Glasses case
- Batteries
- Rubber band
- Bone
- Wood clothespin
- Plastic toys - dog
  - skull
  - cherries
  - spider (rubber)
  - letter
  - teeth
  - number 8
- Cotton patch (Arthur Treacher's Fish and Chips) - strong material
- Hair curler
- Artificial flowers (plastic)
- Razor blade
- Stainless steel knife handle
- Business card (paper) - legible
- Orange peel
- Hair band
- Syringe
- Metal plated object
- Copper wire
- Plastic money holder
- Plastic bottle - legible label
- Bank key holder (rubber/plastic)
- Bread in plastic bag
- Candy cane handle (plastic)
- Metal spring
- Rubber bath mat
- Metal cans - various degrees of decomposition
- Plastic bottle
- Tube
- Plasma bag

LOG OF LYSIMETER FINDINGS: TEST CELL 30
Microbiology

ORGANISM ENUMERATIONS		
	Top Sample	Bottom Sample
Inches Into Refuse		
Std. Plate Count (aerobic)	7.44×10^4	7.85×10^6
Std. Plate Count (anaerobic)	$<1.36 \times 10^4$	8.83×10^5
Clostridium perfringens	9.47×10^5	4.38×10^6
Fungi	3.25×10^6	$<5.48 \times 10^3$
Total Coliforms	$<5.40 \times 10^2$	$<5.49 \times 10^2$
Fecal Coliforms	$<5.40 \times 10^2$	$<5.49 \times 10^2$
Fecal Streptococci	$<5.40 \times 10^2$	$<5.49 \times 10^2$
Clostridium (TSC agar)	1.35×10^5	$<1.37 \times 10^4$
Gram Negative Rods	$<1.36 \times 10^4$	$<1.37 \times 10^4$

METHANE BACTERIA ANALYSIS Composition of Gas in Vials				
SAMPLE WEIGHT (Grams)	% CO_2	% O_2	% N_2	% CH_4
30 Day				
Top				
5.0	79.67	2.05	18.28	0.0
0.5	66.04	4.50	29.46	0.0
0.05	83.93	1.42	14.65	0.0
0.005	64.44	2.91	32.65	0.0
Bottom				
5.0	65.08	2.74	32.18	0.0
0.5	56.30	4.03	39.67	0.0
0.05	40.92	4.54	54.54	0.0
0.005	40.52	5.96	53.52	0.0
60 Day				
Top				
5.0	0.0	11.32	88.68	0.0
Bottom				
5.0	3.81	6.46	77.94	11.79

LOG OF LYSIMETER FINDINGS: TEST CELL 31

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, leachate recycle, buffer buffer addition, nutrient addition

Cell Additives (Reloading): Temperature increase

Refuse Moisture Content (June 1985): Top, 57.1%
Bottom, 54.2%

Test Cell Artifacts:

- Plastic bottles - some labels legible, some not
- Plastic baby shoe
- Plastic toy (fist)
- Toothpaste tube - label vivid
- Comb
- Piece of plastic coat hanger
- Nail polish cap and brush
- Artificial plant
- Lego block (plastic)
- Razor blade - no rust
- Doll leg
- Cigar holder
- Plastic credit card
- Wine bottle cap (plastic)
- Hair band
- Hair curlers
- Blush compact (makeup)
- Metal faucet - not rusted
- Battery
- Plastic mustard bottle
- Plastic doll foot
- Orange juice carton - label legible
- Slipper
- Sock
- Honey pack (plastic) - label legible
- Various metals pieces, cans, wires - various degrees of decomposition
- Plastic devil toy
- Glove
- Hair clip (metal)
- Ribbon (pink)
- Bone
- Coins

LOG OF LYSIMETER FINDINGS: TEST CELL 32

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, buffer addition

Cell Additives (Reloading): No change

NOTE: Cell was not opened for study during this project. This cell is currently part of a recently initiated gas inhibition study using lime or lime/fly ash injection to stop landfill gas production.

LOG OF LYSIMETER FINDINGS: TEST CELL 33

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, buffer addition

Cell Additives (Reloading): Buffer slurry addition

NOTE: Cell was not opened for study during this project. This cell is currently part of a recently initiated gas inhibition study using lime or lime fly/ash injection to stop landfill gas production.

GC/MS ANALYSIS: Cell 33

Concentration, at STP, 25°C

	SAMPLE 1 6/20/85		SAMPLE 2 7/01/85	
VOLUME, ml at STP	94.1		163	
TEMPERATURE, °C	21.7		26.9	
	mg/m^3	ppm	mg/m^3	ppm
Pentane	ND	ND	ND	ND
Tetrahydrofuran	0.65	0.22	0.63	0.21
Freon	1.08	0.21	31.3	6.22
Benzene	1.30	0.40	0.73	0.23
Dichloromethane	2.71	0.77	115	33.4
Hexane	1.08	0.30	30.5	8.74
Toluene	33.5	8.76	20.8	5.57
1,1-Dichloroethylene	ND	ND	ND	ND
1,2-Dichloroethylene	ND	ND	0.06	0.02
1,1-Dichloroethane	ND	ND	ND	ND
o,m,p-Xylenes	249	56.4	91.4	21.3
Ethylbenzene	68.3	15.5	25.6	5.96
Chlorobenzene	ND	ND	ND	ND
Iso-octane	ND	ND	ND	ND
Isopropylbenzene	ND	ND	ND	ND
Propylbenzene	ND	ND	3.66	0.75
Carbon Disulfide	8.02	2.53	112	35.4
Naphthalene	ND	ND	ND	ND
Nonane	ND	ND	ND	ND
Trichloroethylene	ND	ND	0.16	0.03
1,1,2-Trichloroethane	ND	ND	ND	ND
Tetrachloroethylene	ND	ND	0.03	<0.01

ND: Not detected, <5 ng on sample trap
P: Present but not quantified

LOG OF LYSIMETER FINDINGS: TEST CELL 34

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, nutrient addition

Cell Additives (Reloading): No change

Refuse Moisture Content (June 1985): Top, 64.2%
Bottom, 64.3%

Test Cell Artifacts:

- Glasses cases
- Brass tube - discolored
- Piece of mirror
- Metal perfume bottle caps
- Metal button (WLW) - rusted
- Coin purse
- Battery
- Clothes pins (wooden)
- Bra
- Newspaper - decomposed, some print legible
- Key holder (metal)
- Deodorant roller head
- Watch band piece
- Necklace (plastic)
- Metal play penny
- Lighter
- Piece of comb
- Plastic and metal pieces
- Cotton glove
- Piece of rubber tire
- Makeup tube
- Coins
- Sole of shoe - leather
- Plastic bottles - print and colors vivid
- Plastic doll leg
- Doll head
- Bones - piece of pelvis and vertebrate
- Ceramic boot
- Baby bottle nipples
- Piece of brick
- Hair curler
- Plastic letter G
- Rubber ball
- Holy card - image visible
- Stainless steel spoon
- Artificial plant
- Toothpaste tube
- Leather strap
- Stainless knife blade - one end discolored
- Syringe
- Pencil

LOG OF LYSIMETER FINDINGS: TEST CELL 35

PHYSICAL CONDITIONS

Cell Additives (Original): High infiltration, nutrient addition

Cell Additives (Reloading): Nutrient slurry addition

Refuse Moisture Content (June 1985): Top, 72.8%
Bottom, 69.3%

Test Cell Artifacts:

- Golf ball
- Batteries
- Hair band
- Spool
- Spool of thread
- Thong piece
- Hose clamp
- Latch lock (metal)
- Chain link
- Spring (metal)
- Tennis shoes
- Brass hose end (male)
- Lighter
- Cork
- Plastic candy cane
- Glove
- Plastic inflatible
- Leather purse
- Slipper
- Copper wiring
- Coins

LOG OF LYSIMETER FINDINGS: TEST CELL 35
Microbiology

ORGANISM ENUMERATIONS		
	Top Sample	Bottom Sample
Inches Into Refuse		
Std. Plate Count (aerobic)	2.01×10^8	1.47×10^9
Std. Plate Count (anaerobic)	2.78×10^8	9.90×10^6
Clostridium perfringens	1.68×10^8	8.61×10^7
Fungi	1.35×10^6	2.42×10^6
Total Coliforms	$<3.64 \times 10^2$	1.26×10^4
Fecal Coliforms	$<3.64 \times 10^2$	$<3.17 \times 10^2$
Fecal Streptococci	1.45×10^5	4.78×10^2
Clostridium (TSC agar)	1.03×10^7	2.89×10^6
Gram Negative Rods	$<9.15 \times 10^3$	3.78×10^6

METHANE BACTERIA ANALYSIS Composition of Gas in Vials				
SAMPLE WEIGHT (Grams)	% CO_2	% O_2	% N_2	% CH_4
30 Day				
Top				
5.0	60.08	2.46	27.42	10.04
0.5	44.39	4.20	51.41	0.0
0.05	44.94	5.30	49.76	0.0
0.005	45.50	4.12	50.38	0.0
Bottom				
5.0	73.04	3.22	23.74	0.0
0.5	64.03	2.38	33.59	0.0
0.05	78.58	1.05	20.37	0.0
0.005	34.92	6.31	58.77	0.0
60 Day				
Top				
5.0	0.06	11.47	41.64	46.83
Bottom				
5.0	0.0	11.51	88.49	0.0

GC/MS ANALYSIS: Cell 35

Concentration, at STP, 25°C

	SAMPLE 1 6/20/85		SAMPLE 1 Dup * 6/20/85	
VOLUME, ml at STP	100		94.6	
TEMPERATURE, °C	21.7		21.7	
	mg/m^3	ppm	mg/m^3	ppm
Pentane	2.13	0.72	0.90	0.30
Tetrahydrofuran	0.41	0.14	1.08	0.36
Freon	ND	ND	9.71	1.93
Benzene	0.82	0.26	1.18	0.36
Dichloromethane	0.32	0.09	38.4	10.9
Hexane	2.00	0.56	10.7	3.02
Toluene	48.0	12.6	65.2	17.2
1,1-Dichloroethylene	ND	ND	ND	ND
1,2-Dichloroethylene	0.65	0.16	1.50	0.37
1,1-Dichloroethane	ND	ND	ND	ND
o,m,p-Xylenes	120	27.5	513	117
Ethylbenzene	97.1	22.2	138	31.7
Chlorobenzene	ND	ND	ND	ND
Iso-octane	ND	ND	ND	ND
Isopropylbenzene	ND	ND	ND	ND
Propylbenzene	3.00	0.61	5.34	1.08
Carbon Disulfide	10.8	3.42	0.14	0.04
Naphthalene	ND	ND	ND	ND
Nonane	ND	ND	ND	ND
Trichloroethylene	0.13	0.02	0.17	0.03
1,1,2-Trichloroethane	ND	ND	ND	ND
Tetrachloroethylene	ND	ND	ND	ND

ND: Not detected, <5 ng on sample trap
P: Present but not quantified
*: Duplicate sample taken at first sampling, Cell dismantled prior to second sampling

APPENDIX B. MICROBIOLOGICAL MEDIA AND REAGENTS

MEDIA AND REAGENTS

Azide Dextrose Broth

Difco Laboratories, Detroit, Michigan.

Blood Agar

• Blood agar base (Difco)	40	g
Deionized distilled water	1	L

Sterilized at 121°C for 15 minutes. Cool to 50°C and add 50 ml of sheep defibrinated blood from Flow Laboratories, McLean, Virginia 22102.

For anaerobic bacteria, incubate in a GasPak (BBL) jar.

Blood Agar for Streptococci and Clostridia

• Blood agar base (heart infusion, Difco), prepared	1	L
• Sheep blood (Flow Laboratories)	50	ml

Mix aseptically.

Brilliant Green Bile 20% (Difco)

EC Medium (Difco)

Eosin Methylene Blue Agar (Difco)

Ethyl Violet Azide Broth (Difco)

Gases

To grow clostridia and methane bacteria.

- Carbon dioxide, +99% pure
- Hydrogen, 99.95% pure

These were purchased from the Linde Division, Union Carbide Corporation, Charleston, West Virginia.

Gases - Standards used in gas chromatograph

Mixture:

- Carbon dioxide, mole percentage, 34.71%
- Oxygen, 4.15%
- Methane, mole percentage, 44.67%
- Nitrogen, 16.47%

Matheson Gas Co., Dayton, Ohio

Iron Milk

Dowell and Hawkins (1976)

• Skim milk powder (BBL)	100 g
Iron wire, 2 cm	1 per tube
Deionized distilled water	1 L

Sterilize at 115°C for 20 minutes.

Lauryl Sulfate Broth (BBL)

MacConkey Agar (BBL)

Methanogenesis Medium

Donnelly and Scarpino (1984)
Enrichment broth for methane-producing bacteria.

• Sewage Sludge	300 ml
KH_2PO_4	0.5 g
K_2HPO_4	0.5 g
NaCl	1.0 g
$(NH_4)_2SO_4$	0.5 g
$MgSO_4 \cdot 7H_2O$	6.2 g
$CaCl_2 \cdot 2H_2O$	0.13 g
Reasurin	0.001 g
$MnSO_4 \cdot H_2O$	0.5 g
$FeSO_4 \cdot 7H_2O$	0.2 g
$CoCl_2 \cdot 6H_2O$	0.17 g
$ZnSO_4 \cdot 7H_2O$	0.18 g
$CuSO_4 \cdot 5H_2O$	0.02 g
$Na_2SO_4 \cdot 12H_xO$	0.018 g
H_3BO_4 (Boric Acid)	0.01 g
$Na_2MoO_4 \cdot 2H_2O$	0.01 g
Trypticase (or tryptone)	2.0 g
Yeast Extract	2.0 g
Na Formate	2.0 g
Na Acetate	2.0 g
Water	700 ml

Place 100 ml of medium in 150 ml glass vials and flush with oxygen-free nitrogen. Sterilize at 121°C for 15 minutes. Re-flush with oxygen-free nitrogen and secure mouth of vials with serum sleeve rubber stoppers. Cool.

• 50% $NaHCO_3$	0.25	ml
• Escherichia coli ATCC 13706, overnight culture grown at 37°C in brain heart infusion broth.	0.50	ml

Mineral Oil

Society of American Bacteriologists (1957)
Sterilize in 100 ml amounts at 121°C for 60 minutes.

(0.1%) Peptone Water

Standard Methods (1980)
A diluent for bacterial cultures

• Bacto-peptone (Difco)	1.0	g
Deionized distilled water	1	L

Sterilized at 121°C for 15 minutes.

PSE Agar - (Bile Esculin Azide Agar- Gibco Laboratories, Madison, WI 53713)

Standard Methods Agar (BBL)

Tryptone Sulfite Cycloserine (TSC) Agar

Duncan and Harmon (1976)
To enumerate Clostridium perfringens

• Trypticase soy broth (BBL)	30.0	g
Sodium metabisulfite	1.83	g
Ferric ammonium citrate	1.0	g
Agar (Difco)	20.0	g
Yeast extract	5.0	g
Distilled water	1	L

Heat to dissolve ingredients. Adjust pH to 7.6. Sterilize at 121°C for 10 minutes. Cool to 50°C. To each liter of medium, add 10 ml of 4.0% D-cycloserine (sterilized by the membrane filter) and 80 ml of sterile 50% egg yolk in saline.

APPENDIX C. QUALITY ASSURANCE

The data quality criteria that were of concern in this project and which are addressed in this appendix are precision, accuracy, completeness, representativeness and comparability of the data. Each of the following sections describes one of these criteria. The final section summarizes the data quality for all analyses including those analyses without corresponding QA information. This summary discusses problems that were encountered and the overall usability of all of the data.

PRECISION

Precision is defined as the measure of mutual agreement among individual measurements of the same property. This is monitored by comparing the results of split or duplicate samples. The goal is always to minimize the difference between the replicate results. Precision for all analyses has been evaluated in one of two ways. In most cases the precision has been evaluated as described in "Calculation of Precision, Bias and Method Detection Limit for Chemical and Physical Measurements". The replicate analyses were evaluated for any apparent trends between the mean values and the standard deviation and/or the coefficient of variation of the data pairs or triplicates. In all cases, the standard deviations of the replicate results decreased with decreasing concentrations. The coefficient of variation showed no clear relationship across concentration ranges. Therefore, precision for most analyses has been expressed as a standard deviation derived from the mean coefficient of variation from each data set. The standard deviation is derived from the coefficient of variation according to the following equation:

$$s = CV\ X\ /\ 100$$

where: s = standard deviation
CV = coefficient of variation
X = sample concentration

For the microbiological analyses at least two plates per dilution were set up for each plate count procedure. These replicate plates were simply sub-samples of the same homogenized sample. Evaluating the results of these replicates provides information on the variability associated with the method and the analyst technique. In many cases even at the lowest dilution used ($1x10^{-1}$) there were no colonies formed. When no colonies were formed the results were not included in any of the QC calculations.

In order to estimate the effect sub-sampling had on result variability

one duplicate sample was analyzed on each microbiological sampling day. This duplicate was a separate sub-sample of the bulk (1 kg) micro sample taken at each lysimeter sampling location. This duplicate was then homogenized and diluted as necessary for analysis. Since there were only three actual duplicate samples and since so many of the results showed no microbial populations at the lowest dilutions used it was not meaningful to determine the standard deviation of the results. It is helpful to examine these results in terms of the deviation about the mean. This provides some direct indication of how far two duplicate results differ from the reported mean value.

$$\%D = \frac{\overline{X} - X_n}{\overline{X}} \times 100$$

where: $\%D$ = % Deviation from the mean
$\overline{X}$ = Mean Concentration of duplicate results
X_n = One of the duplicate results

This information can be loosely interpreted in the following manner. An overall average deviation about the mean of 51% suggests that a mean colony count of 53, for example, is derived from duplicate values of 26 and 80. When applied to an entire data set, it could be said that for any duplicate analyses performed of this particular analysis, the reported mean value will, on the average, be $\pm$ 51% of the actual values obtained.

Gas Analysis

In order to obtain some feel for the precision of the gas analysis duplicate samples were taken from a randomly selected lysimeter on one of the sampling days. This was a field duplicate which takes into consideration variability resulting from sampling technique, sample transport, sample storage, sample preparation and sample analysis. The duplicate results obtained for the two samples taken from cell 35 on 6/20/85 were presented on page 25. Twelve of the target compounds were found in both samples. One compound, freon, was reported present in one of the samples but not in the other. Nine of the compounds were not detected in either sample. The estimate of intralaboratory short term precision for all compounds detected in both samples is $s = 0.61X$ where X is the mean concentration of the duplicate results and CU represents the concentration units.

Standard Plate Count: Aerobic

Precision measurements of microbiological plate counts are based on the actual counts prior to dilution corrections of the replicate plates. The estimate of intralaboratory, short term precision for all aerobic standard plate counts recorded in the sample lot is $s = 0.47X$ CU, where X is the mean count of the replicate plates and CU represents colonies counted. This estimate is based on replicate analysis of fourteen samples which represent approximately 82% of the total samples analyzed. The actual plate counts, not corrected for dilutions, ranged from 1 to 1100 in the refuse samples.

Analysis precision based on the deviation about the mean of the actual duplicate pairs was determined for this analysis. Mean reported values are, on the average, ± 48% of the actual duplicate data values obtained.

Standard Plate Count: Anaerobic

The estimate of intralaboratory, short term precision for all counts recorded in the sample lot is s = 0.38X CU, where X is the mean count of the replicate plates and CU represents colonies counted. This estimate is based on replicate analyses of thirteen samples which represent approximately 76% of the total samples analyzed. The actual plate counts, not corrected for dilutions, ranged from 4 to 1500 in the refuse samples.

Analysis precision based on the deviation about the mean of the actual duplicate pairs was determined for this analysis. Mean reported values are, on the average, ± 25% of the actual duplicate data values obtained.

Gram Negative Rods: MacConkey Agar

The estimate of intralaboratory, short term precision for all counts recorded in the sample lot is s = 0.36X CU, where X is the mean count of the replicate plates and CU represents colonies counted. This estimate is based on replicate analyses of two samples which represent approximately 12% of the total samples analyzed. The actual plate counts, not corrected for dilutions, ranged from 1 to 237 in the refuse samples.

The samples chosen for duplication all showed no counts at the lowest dilutions analyzed. Therefore, there was no estimate of actual duplicate precision.

Clostridium Perfringens: Tryptone Sulfite Cycloserine Agar

The estimate of intralaboratory, short term precision for all counts recorded in the sample lot is s = 0.26X CU, where X is the mean count of the replicate plates and CU represents colonies counted. This estimate is based on replicate analyses of nine samples which represent approximately 53% of the total samples analyzed. The actual plate counts, not corrected for dilutions, ranged from 3 to 2800 in the refuse samples.

Analysis precision based on the deviation about the mean of the actual duplicates was determined for this analysis. Mean reported values are, on the average, ± 50% of the actual duplicate data values obtained.

Fungi: Rose Bengal Agar

The estimate of intralaboratory, short term precision based on the standard deviation and coefficient of variation was not determined on this anaylsis. Analysis precision based on the deviation about the mean of the

duplicate pairs was however, determined. Mean reported values are, on the average, ± 45% of the actual duplicate data values obtained.

Gas Composition (Methane Producers)

All samples were set up in 2 sample vials for each weight analyzed. Out of all of the samples analyzed (30 and 60 day incubations) 53% of the samples showed no methane production in either sample bottle. Another 25% had methane production in one bottle but not the other. Only 22% of the duplicate sample bottles had methane production in both bottles. All QC results were based on this 22% or 13 samples only. The estimate of intralaboratory, short term precision for each concentration found in the sample lot is $s = 0.66X$ CU, where X is the mean concentration of the duplicate pairs and CU represents the concentration units of the result.

ACCURACY

Accuracy is defined as the degree of agreement of a measurement with the true value of the measurement. Often, a measurement of the accuracy of the measurement process is obtained through the analysis of QC standards. If the measurement process is functioning normally, results are expected to fall very close to 100% recovery of the standard.

Gas Analysis

All gas samples were spiked with 5 ul of an internal standard solution prior to sample preparation. This solution not only contained the three compounds to be used for quantitation but also three surrogate QC standards. These surrogates were D4-1,2-Dichloroethane, D8-Toluene and 4-Bromofluorobenzene. Recoveries of these compounds provide a measure of the accuracy of the measurement process as well as the extent of interferences introduced into the process as result of a complex sample matrix. The recoveries obtained on these compounds for all samples analyzed including field and lab blanks can be seen in Table C-1. These recoveries suggest that a slight negative bias exists in the results of the lower molecular weight compounds. That is, reported values may be lower than actual values. Those compounds with high molecular weights may relect a slight positive bias. That is, reported results may be somewhat higher than true values. Those compounds remaining show little to no bias in the reported results.

Microbiological Analyses

Unfortunately, standards are not available for the microbiological analyses. There are no standards with known microbial counts to quantitatively assess the validity of the microbial measurements. However, it was possible to qualitatively evaluate the accuracy of the measurement process by evaluating the prepared media against reference cultures. These cultures were derived directly from the American Type Culture Collection or indirectly from Difco. These reference cultures can be seen in Table C-2.

Table C-1. SURROGATE RECOVERIES

Compound	Mean Recovery %	Standard Deviation %	Minimum Recovery %	Maximum Recovery %
D4-1,2,-Dichloroethane	80	26	56	170
D8-Toluene	99	6	80	104
4-Bromoflourobenzene	114	21	70	142

TABLE C-2. MICROBIOLOGICAL REFERENCE CULTURES

CULTURE NAME	ATCC NUMBER
Acinetobacter calcoaceticus	e23055
Clostridium novyi	e19402
Clostridium perfringens	e3624
Escherichia coli	25922
Pseudomonas aeruginosa	27853

a: American Type Culture Collection, Rockville, Maryland 20852

COMPLETENESS

Completeness is defined as the number of usable results obtained expressed in terms of the total number of results expected for each analysis. Gas analyses were 71% complete. Originally five samples, a duplicate and a blank were taken on two different days in the early part of the project. Due to difficulties encountered with the original 2 liter sample volume the entire gas analysis had to be done again. Gas sample volumes were decreased however, one cell had been dismantled prior to the first re-sampling. Therefore, only four samples a duplicate and a blank were obtained. Before a second set of samples could be obtained it was necessary to dismantle two additional cells. Only two cells remained to be sampled. Unfortunately, due to the number of traps used in the original 2 liter sampling (14 traps) and in the first re-sampling (6 traps) insufficient traps remained to obtain a duplicate and a blank sample on the second re-sampling day. Therefore, 14 samples were originally planned for this project but only 10 were actually taken and analyzed.

The micro analyses were 98% complete. Even though many of the results had to be reported as less than some value, which in some cases was relatively high, the data generated provided some feel for the relative numbers of the various types of organisms that were present. Since this fulfilled tha microbiological objectives for the study the results are considered complete. The 2% of non-usable results refer to the samples that still had not generated any methane in the methane former analysis. Since the 90-day incubation was not completed for the samples it is not possible to say whether there were really no methane formers present in the samples or if the results simply reflect the fact that the samples did not incubate for 90 days. Therefore, 2% of the results are not usable and are not considered complete.

REPRESENTATIVENESS

Representativeness is defined as the degree to which data accurately and precisely represent a characteristic of a population. This is generally addressed through adherence to prescribed sampling procedures which ensure that samples taken for analysis truly represent the entire material being sampled. Gas samples were taken directly out of gas lines coming from the lysimeter. Since there was sufficient pressure in the tanks to push the gas into the sample traps it was not necessary to use a pump to pull the gas into the traps. This eliminated one area where air contamination is often encountered. There were no leaks determined in any of the connections therefore the samples were truly representative of gas generated in a lysimeter setting. Since the full-scale landfill is subjected to atmospheric interface and dispersion of the gas within the landfill the levels of the trace constituents may be somewhat higher in the lysimeter gas where lateral dispersion is not possible and atmospheric interface is prevented by the steel walls of the test cell. In spite of possible concentration differences the actual compounds found in the lysimter gas are certainly representative of the compounds that would be present in any gas generated by a municipal waste.

Although every reasonable attempt was made to ensure representativeness of the waste samples, given the nature of the refuse in the lysimeters and the volume sampled (1 kg) relative to the total volume in the lysimeters, it would be reasonable to assume that obtaining samples representative of the entire lysimeter would be extremely difficult, if not impossible. The refuse was clearly heterogeneous throughout and even though samples were taken such as to minimize this problem, there is undoubtedly still some effect. Furthermore, microbiological samples were taken so that the non-biodegradable constituents (e.g. glass, plastic, etc.) were intentionally excluded. It would be reasonable to assume that the samples taken represent typical municipal landfill samples; however, they do not necessarily represent the entire contents of the lysimeter from which they were obtained.

COMPARABILITY

Comparability is defined as the confidence with which on data set can be compared to another. Data generated by this project are readily comparable to other similar data, since all methods (with the exception of the methane producer analysis) are standard procedures. Furthermore, all results have been reported in standard reporting units. All solid waste results have been reported in terms of dry weight in order to maximize comparability. All gas results have been reported in terms of mg/m^3 as well as ppm so they will be readily comparable to any data in the literature. When data are compared with other similar data, the problems encountered with sample representativeness should be kept in mind. The overall effect would tend to make data comparable in a broad, general sense only.

SUMMARY

Gas Analysis

The gas sample matrix was known to be very complex. In fact, the samples analyzed on 5/20/85 had such high levels of some compounds that the samples were damaging the instrumentation. Even when the sample volumes were decreased by a factor of 20 many compounds were present at concentrations that were near or above the dynamic range of the instrumentation. When this is taken into account with the bias associated with the recoveries it is reasonable to say that the concentrations reported should be regarded as approximate.

Microbiological Analyses

MPN Tests: Total Coliforms, Fecal Coliforms, Fecal Streptococci and *Clostridium perfringens*

Even though duplicate samples were analyzed for each of these tests no relavent QC information was generated since most of the results had to be reported as less than some value. No additional QA/QC procedures were performed on the MPN tests beyond those built into a traditional MPN test. Each

MPN analysis is designed such that several nested levels of isolation and identification ensure that a high percentage of the results will be accurate. Even though five fermentation tubes were used, precision of the results obtained is generally not considered to be of a high order. This can be seen in the tables of the MPN 95% confidence limits found in Standard Methods for the Examination of Water and Wastewater. Although the MPN index was used to estimate the true bacterial density in the samples, the 95% confidence limits have not been included herein. Caution must be exercised when interpreting the significance of the MPN results from this project. It should be stressed that the most significant information obtained from the MPN tests is that the indicator organisms survived in relatively low numbers if at all.

Plate Counts: Standard Methods-Aerobic, Standard Methods Anaerobic, MacConkey, Rose Bengal

Precision for all plate counts is based on the actual number of colonies counted on replicate plates. Considering the potential variability when dealing with microorganisms, the duplication seen on this data is not surprising. The plate counts showed more variability between replicate plates than anticipated. This can probably be attributed to the fact that almost all plates that showed growth and could be counted were from the lowest dilutions used. As discussed in the microbiology discussion of the text (Section 5, page 31) the original homogenized sample was very difficult to work with. Homogenization is an attempt to create a homogeneous sub-sample but given 80 g of sample in 320 ml of water it is doubtful that true homogeneity is achieved. When this homogenized sample is serially diluted it approaches homogenetiy and therefore less variability is found between replicate plates at higher dilutions. Conversely, greater variability is experienced between replicate plates of lower dilutions. This is essentially a reflection of the method and until microbiological methods are established specifically for solid waste this level of variability will continue to be seen. Accuracy of these analyses relied heavily on analyst experience. It is difficult to eliminate this dependency; however, it is minimized through the use of Standard Reference Cultures which ensure that the desired organism(s) will, in fact, grow on the media prepared for that purpose. For the purposes of this project, the data generated through the plate counts confirms the presence of many organisms in relatively high numbers.

Enrichment Tests: Methane Producers

The methane producer test was basically used as a qualitative test for the presence or absence of methane producing bacteria. This was accomplished by quantifying methane levels in the test vials. The data generated are clearly usable for this purpose.

Based on the assumption that the data generated on this project are intended to be used in a general, relative sense, all of the data can be considered acceptable for this purpose. Although QC data was not or could

not be generated for all analyses, this does not seriously effect the useability of this information.